Reducing the Oilfield’s Environmental Footprint

Footprints in the sand get washed away every time the tide rises. But for the environment there is no tide, and our impact on the world may last years or decades. A challenge for the oil industry is to develop technology to make smaller and smaller footprints.

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Technology is now being applied to limit the environmental impact of exploration and production. This means using less of potentially toxic products and reducing the discharges left behind.

Offshore, the prime concern is the effect of cuttings contaminated with drilling fluid which have traditionally been dumped on the seabed. Onshore, seepage of waste chemicals and contaminated washwater into the ground is causing increasing problems.

Facing up to Oil-Base Mud in the North Sea

Unlike offshore USA, dumping of cuttings drilled using oil-base mud (OBM) is still permitted in the North Sea. Base oil attached to these cuttings accounts for 90 percent of the area’s hydrocarbon pollution attributed to the offshore oil and gas industry.1 In 1987, the UK Department of Energy estimated that up to 60,000 tons (t) of oil were dumped in the North Sea in this way—nearly half of the total hydrocarbon pollution from all industries (next page).

Since 1987, North Sea drilling has increased and with it the rate of pollution. Sedco Forex estimates that for each North Sea well, 1,000 t of OBM and cuttings are discharged into the ocean. But regulations are tightening. Authorities in Europe are aiming to dramatically reduce the level of contamination from drill cuttings.

Oil-base mud has a continuous phase of oil. Calcium chloride brine, typically used as the internal or emulsified phase, provides an osmotic force to balance formation activity. This is important for maintaining borehole stability. Primary emulsifiers, secondary emulsifiers and wetting agents stabilize the emulsion and add oil-wetting characteristics. Further additives activate the emulsifiers, control filtration and increase fluid viscosity. The toxicity of individual additives does not necessarily correlate to the overall toxicity of the fluid. And legislation generally looks at the total mud, not the constituent parts.2

Originally OBM was formulated with diesel fuel which has a high toxicity, but in 1981, OBM using low-toxicity base oil was introduced. Even so, these low-toxicity systems still have a significant effect on the marine environment. Cuttings are traditionally dumped on the seafloor and even the most efficient mud removal equipment leaves these cuttings contaminated with significant quantities of oil-base mud. A buildup of base oil together with the cuttings on the seabed creates the following problems in the subsea environment:

- Increased concentrations of hydrocarbons and mud components, like barium sulfate in seafloor sediment, biota and water
- Burial or smothering of seabed organisms
- Alteration of flora and fauna distribution and diversity on the seabed
- Sublethal effects, like tainting of fish flesh—of particular concern to the fishing industry.

The intensity and extent of adverse effects depend on the chemical composition and toxicity of the OBM together with the amount and method of discharge of the cuttings and their dispersion. Dispersion on the seabed is influenced by water depth, currents induced by wind and tide and regional hydrology.

Increased concentrations of hydrocarbons near offshore installations which are attributable to OBM discharges commonly extend up to 2 kilometers (km) [1.2 miles] in the direction of the local current, but rarely exceed 5 km [3 miles]. Perpendicular to this current, concentrations are not usually

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detected beyond 1 km [0.6 mile]. Distribution is more widespread in shallow areas where sediments are subject to dispersion by wind-induced turbulence—during storms this effect can be felt in water deeper than 100 meters [300 feet].

Effects on species diversity and population of seabed organisms are generally observed up to 1 km from the point of discharge. However, where currents are swift and the drilling activity extensive, this distance may be extended to 25 km [15.5 miles] in the direction of greatest water movement.

Pollution monitoring in the Norwegian sector of the North Sea has claimed detecting impact from OBM cuttings up to 5 km from the Statfjord C platform and in a 3-km [2-mile] radius around Ekofisk platforms.\textsuperscript{3, 4}

Clearly, OBM cuttings have a major impact on the marine environment and control of their discharge has gradually become more stringent around the world. First to act was the US. In 1970, the National Environmental Protection Act was enacted. Soon after, the Environmental Protection Agency (EPA) was established. Over the years, a series of guidelines has been put in place covering drilling fluids and cuttings disposal.\textsuperscript{5}

In July 1986, US federal waters came under the National Pollutant Discharge Elimination System (NPDES), a program administered by the federal EPA or state environmental agency. This program regulates discharges into seawater and onshore surface water—it also extends to groundwater.\textsuperscript{6} All offshore discharges must have an NPDES permit. Discharge of whole OBM or cuttings drilled with OBMs was prohibited and a requirement to perform bioassays of water-base muds and the LC50 toxicity test was made compulsory (see "Defining Toxicity," next page).

In Europe, legislation varies by country. However, the Regional Inter-Governmental Body to Harmonize Controls on Discharges to North Sea and NE Atlantic—or Paris Commission (Parcom)—was established in 1978 to develop a coordinated approach. In June 1988, agreement was reached on ways of reducing marine pollution from drilling muds and drill cuttings.\textsuperscript{8}

The agreement banned discharge of whole OBM at sea and prohibited its use in the upper sections of wells. Use of diesel-base mud was banned, though diesel can still be employed during some workover
functions, during perforation and to help free stuck pipe during drilling.

National authorities participating in Parcom are required to insist that operators seek prior authorization wherever OBM is used offshore. This authorization should be given only where use of OBM can be regarded as essential for geological, safety or economic reasons.

The economic disclaimer gives national authorities considerable scope for interpretation. Parcom identifies two cases where economics justifies use of OBM: when deviated drilling is necessary and when waterbase muds would be prohibitively expensive.

In 1990, Parcom agreed on a set of guidelines to harmonize procedures of approval, evaluation and testing of offshore chemicals and drilling muds. These tests take toxicological data from three kinds of marine organisms—algae, herbivores and sediment reworking species—rather than the single species, usually shrimp, used for the widely accepted LC50 tests.

Two years ago, Parcom also set a target for the maximum oil content of cuttings dumped in the sea—100 grams of oil per kilogram (g/kg) of dry cuttings. The UK, by far the North Sea’s largest user of OBM, currently sets a limit of 150 g/kg. This will be cut to 100 g/kg at the end of 1991, with zero discharge planned for 1994. Other North Sea states already maintain 100 g/kg requirements and Norway is poised to impose tighter regulations.

In 1988, 37 wells were drilled in Norway using OBM. Around 19,500 t of oily cuttings were produced which in total led to the discharge into the sea of more than 1,700 t of oil. Oil companies operating in the sector estimate that in 1989 total discharged oil had been reduced to 971 t, and since 1987, the amount of oil discarded has been reduced from 30 to 17.3 tons per well.

To reduce this quantity of discharge yet further, the Norwegian State Pollution Control Authority recently drafted new regulations. If accepted, these regulations will prohibit free discharge of oily cuttings into the seawater from 1991. This covers all new development and exploration drilling except when safety and geological considerations necessitate the use of OBM. Then, discharge of cuttings with an oil content of up to 10 g/kg of dry cuttings may be permitted. Production drilling that has already been granted a permit, and currently has to meet 100 g/kg, will have this cut to 60 g/kg in 1991 and to 40 g/kg by the start of 1993.

One of the first major developments to be affected by Norway’s tightened legislation is Saga Petroleum’s Snorre field where drilling concentration greater than 10,000 milligrams per kilogram (mg/kg). Alternatively its LC50 concentration must not be less than 30 times that of a reference diesel-base mud.

Another test, not usually applied to drilling fluids, is the LD50. This determines the dosage required to kill half the test animals expressed as milligrams of material per kilogram of body weight. Highly toxic substances typically achieve an LD50 at 50 mg/kg or less.

Biodegradability measures the persistence of a material in the environment and is used to estimate how long complete degradation is likely to take. Percent biodegradability expresses the relative utilization of oxygen for biological action versus oxygen required for total degradation by chemical reaction. Percent biodegradability is defined as 100 times the ratio of biochemical oxygen demand (BOD) to chemical oxygen demand (COD) or the ratio of BOD to theoretical oxygen demand (ThOD).

BOD defines the amount of oxygen required by microorganisms to degrade a given amount of a product and is expressed as parts of oxygen per part of material being degraded. In practice this test is carried out by exposing the product to secondary sewage effluent as a source of microorganisms in a neutral aqueous medium. Oxygen content is measured at 5-, 10- and 20-day intervals from which BOD is calculated.

COD is the amount of oxygen required to degrade all organic matter in a given amount of material. It is determined by subjecting a given weight of material to an acid solution of sodium dichromate and then measuring the amount of dichromate reduced to chromium (III). The results are expressed in terms of parts of oxygen per part of material being degraded.

ThOD is the amount of oxygen required to convert an organic material to carbon dioxide and water.

from a semisubmersible rig is underway. The company will employ water-base mud for as much of the well as possible but in some sections oil-base fluids will have to be used. Saga does not have a permit to dump oily cuttings, so these will be brought ashore for treatment.

Although Norwegian legislation is much stricter than that of other North Sea countries, there is a clear trend towards eliminating discharge of oil-contaminated cuttings throughout Europe. To meet new regulatory demands, operators face an array of options but few obvious solutions. Five strategies are being considered: cleaning the cuttings offshore with improved equipment; disposing cuttings onshore; controlling disposal of cuttings using seabed containers; injecting cuttings in slurry form into old wells or down annuli; and drilling with alternative mud systems (see “Five Strategies for Meeting OBM Regulations,” next page).

A strategy to reduce the environmental impact of drilling—though not necessarily to meet regulations—is reducing the quantity of mud and cuttings. By designing and maintaining a drilling fluid to optimize wellbore stability, the hole stays closer to gauge and volumes of drilling fluid and cuttings are reduced.

Efficient mixing and monitoring of mud are paramount in achieving this. Yet most rig site techniques have changed little since the early 1950s. Complete tests of the mud’s physical condition are normally taken only two or three times a day. These one-point determinations allow substantial error—it is not unusual for 300 cubic meters (m³) [1,900 barrels] of mud to be checked using a 1-liter [0.3-gallon] sample. The results determine the chemical additions and solids control operations for the next 8 to 12 hours.

The poor performance of many current mud systems is illustrated by research in the US by the American Petroleum Institute (API). The API estimates that on average, 11 barrels of water-base mud are consumed and 4 barrels of cuttings produced for every barrel of solids removed. The ratio of volume of mud used plus volume of cuttings to volume of mud gives a measure of drilling efficiency—“mud/cuttings ratio.” In the case of the API study, this ratio is 15:1. Significantly lower values have been compiled by Sedco Forex from wells worldwide (see “Mud-to-Cuttings Ratios,” above). But even these figures allow considerable room for improvement. At its most efficient, drilling with OBM has a mud/cuttings ratio of 3:1.

To increase efficiency, improved measurement equipment is being developed. Process control techniques are being applied to mud by Sedco Forex’s MUDSCOPE operations service which includes mixing and maintaining of drilling fluids and optimizes the operation of solids removal equipment. Mud poses many problems. A complicated chemical system is subject to changing temperature and pressure. During drilling, solids are added and removed; the particle type and size distribution of these solids changes continuously. The liquid phase evaporates and its chemical composition is altered by interaction with the formation.

One of mud’s prime functions is to remove drilled solids. Concentration of these solids in the mud affects physical properties like density, rheology and filtration and determines the extent of dilution required to keep the mud within specification. As process control techniques are refined, the volumes of mud dilutions required will be substantially reduced and the total volume of mud used to drill a well will be reduced.

Cleaning Up Fracturing

Environmental challenges onshore are no less significant than those offshore. Once again, problems stem from using potentially toxic chemicals, an extreme case being large-volume stimulations. These require truckloads of chemicals that if not managed properly can contaminate the wellsite. A 500,000-gallon [2,000-m³] fracturing treatment consumes about 700 sacks of dry materials and 35 drums of chemicals. Traditionally all this is handled and mixed at the wellsite; spills occur, empty sacks and broken pallets remain on the lease, and disposal problems for unused premixed fluids can persist long after job completion.

The quantity of chemicals required usually cannot be reduced, but how they are brought to location and mixed prior to pumping has now been revolutionized by the Precision Continuous Mixer (PCM) unit.
**Cleaning Cuttings Offshore**

Several options include centrifuges, extraction with solvents and evaporation of oil through heat. The prime limitation is whether the rig or platform can accommodate the treatment equipment.

A common cuttings cleaning process involves adding additional base oil to the cuttings and passing them through two stages of centrifuge (right). Alternatively, solids are washed with an aqueous surfactant, then passed over shakers through a decanting centrifuge and into a three-phase separator (below, left). The wash solution is then recycled and used to clean more cuttings. Neither method is capable of meeting Norway's proposed standards.

BP Chemicals Ltd has developed a cleaning fluid that displaces oil instead of dissolving or emulsifying it. The cleaning fluid can be used with a wash drum cuttings cleaning system incorporating drying screen, two-phase decanter and three-phase disc stack centrifuge (below, right). This is reported to reduce oil to

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*Cleaning OBM cuttings with surfactant plus wash drum. Solids are washed in an aqueous surfactant, then passed through three stages to separate liquid from fines which are then dumped.*

*Cleaning OBM cuttings using an improved wash drum system. A new cleaning fluid developed by BP is added to cuttings and passes into a wash drum. The oil is displaced from the cuttings rather than dissolved or emulsified. Conventional equipment can then be used for separation.*
around 30 g/kg and also to allow for the recovery of the base oil.¹

These systems are quite rough on the cuttings and can reduce their size, increasing surface area. This changes the surface chemistry and could increase the concentration of heavy metals leaching out of the solids; the particles could also float away—one way of avoiding this would be to compact the solids into bricks prior to dumping.

Systems that evaporate oil from cuttings are also under development. At the heart of this equipment are burners that fire recovered hydrocarbons, produced gas or diesel. Cuttings are heated to a controlled level and entrained hydrocarbons vaporized. In a distillation unit, these vapors are then condensed and recovered base oil reused. The system’s manufacturers claim that oil content can be cut to less than 5 g/kg.²

A pilot system is due for delivery this year onshore Norway, where cuttings currently brought ashore are being stored. If successful, an offshore version weighing 35 to 50 tons will be built.

**Transporting Cuttings Ashore**
The drawbacks of this option are logistics. Transportation is often disrupted by bad weather, and in extreme cases this holds up drilling. Increased crane operations to load and transfer containers of cuttings increases accidents, while storage of cuttings increases rig loading and reduces storage available for consumables like casing. The advantages are that, once onshore, disposal need not be carried out immediately, and equipment can be selected without weight constraint. However, little is known about the long-term effect of dealing with cuttings onshore. Disposal could create new environmental problems.

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2. Fox CF. “Putting the heat on oily cuttings,” *Offshore Engineer* (September 1999): 132-134.
Controlled Disposal
This concept calls for the placement of cuttings on the seabed inside a container. Within the container, natural degradation would occur—like a subsea compost heap—leaving the surrounding area free from contamination. In a system devised by concrete construction specialist Norwegian Contractors (previous page), cuttings and oxygen-enriched flush water are delivered via a line to the container. A return line carries the water to surface. In the oxygen-enriched environment in the container, aerobic microorganisms feed on the organic components of mud and cuttings to produce gases, such as hydrogen sulfide, carbon dioxide and methane. These gases are mainly dissolved in the continuously circulating water and are separated out and vented at surface.

Before a rig is demobilized, the quantity of oil in the returning water is measured. If this meets standards, the container is left in place but opened to seawater, and slower anaerobic activity takes over. The rate at which this proceeds is unknown, but Norwegian Contractors reports that complete degradation of oil inside the cuttings pile could take decades.

Injecting Slurried Cuttings
This method, only experimental so far, involves creation of a slurry out of the cuttings. This slurry is then pumped down the annulus of the well being drilled at sufficient pressure to fracture formation and allow injection of the cuttings slurry. An alternative to annular injection is for the slurry to be injected into disposal or disused wells.

One scheme being investigated by BP Petroleum Development Ltd proposes injection of a mud/cuttings slurry into formations below the shoe of the 20-inch casing. Key factors for success would be the ability of the receiving formation to accept the volumes of slurry envisaged at the necessary rate of injection, the efficient crushing of the cuttings on surface to produce a self-suspending slurry and annulus access—particularly tricky from a semisubmersible where the riser system and connection at the seafloor would become much more complicated.

Drilling with Alternative Mud Systems
Treating OBM cuttings to reduce oil content could be seen as treating the symptom rather than the cause. An alternative is to develop mud systems that behave like OBM but are environmentally acceptable.

A common argument for employing OBM is its ability to stabilize shales and salt zones, which are traditionally difficult formations to drill with water-base mud. But a new generation of muds has just reached the market. Two systems launched by Aker Drilling Fluids Ltd. and Baroid Corp. use emulsions similar to OBMs but are based on a complex ether and an ester, respectively. Because these chemicals have weaker carbon-hydrogen bonds than the base-oil in OBM, biodegradation should proceed more rapidly.

The new mud systems, which cost more per barrel than conventional OBM, are in trial with the oil companies. The muds will have to prove to operators that they can withstand high temperature, pressure, salinity contamination and influxes from the formation while still offering as consistent performance as OBM.
Introduction in 1988, there are now 14 of these units in service (above).

The main impetus for development of the PCM mixer was to perform more cost-effective fracture treatment. A major benefit, however, has been to reduce the environmental impact of stimulation treatments. The PCM unit cleans up wellsite operations and reduces the amount of premixed chemicals and the number of partly used drums of unblended chemicals left at the end of a job (see "Container Savings With Continuous Mixing," right).

The PCM was developed to make maximum use of the polymer slurry system and provide a pressure feed to the POD Blender where sand is added to the fracturing fluid prior to being pumped downhole. Use of a polymer slurry allows continuous mixing at up to 70 barrels/min [11 cubic meters/min]. Consequently, huge volumes of fracturing fluid need not be premixed, allowing flexibility in job design—concentrations of additives can be changed while a job is in progress, by one person at the PCM control console.

By mixing the fluid as it is pumped, no preblended fluid is left in frac tanks. In conventional operations this can happen either because too much was mixed or because the hydrostatic head of a tank is reduced as it empties. Fluid at the bottom of tanks cannot easily be extracted and typically represents at least 7 percent of the volume.

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## Container Savings With Continuous Mixing

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Quantity Required</th>
<th>Containers Eliminated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gelling agent</td>
<td>25,000 lb</td>
<td>500 sacks</td>
</tr>
<tr>
<td></td>
<td>[11,340 kg]</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>1,000 gal</td>
<td>20 drums</td>
</tr>
<tr>
<td></td>
<td>[3,785 liters]</td>
<td></td>
</tr>
<tr>
<td>Clay stabilizer</td>
<td>500 gal</td>
<td>10 drums</td>
</tr>
<tr>
<td></td>
<td>[1,890 liters]</td>
<td></td>
</tr>
<tr>
<td>Crosslinker</td>
<td>250 gal</td>
<td>5 drums</td>
</tr>
<tr>
<td></td>
<td>[945 liters]</td>
<td></td>
</tr>
<tr>
<td>Oxygen scavenger</td>
<td>10,000 lb</td>
<td>200 sacks</td>
</tr>
<tr>
<td></td>
<td>[4,545 kg]</td>
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</table>

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The Precision Continuous Mixer mounted on a single 46-foot [14-meter] trailer. Fourteen of these units are currently in use.

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Over chemicals remain uncontaminated in the PCM unit’s tanks.

Continuous mixing also provides less time for bacteria in mix water to degrade polymers and reduce frac fluid viscosity. Hence, less bactericide is needed than with premixing.

But it is not just a question of cutting chemical usage. All leftover, contaminated fluid has to be disposed of at a cost of up to $500 per drum. This year in North America alone, Dowell Schlumberger (DS) expects to spend over $500,000 for disposal of drummed wastes. Such a sum could put another PCM unit into service.

And not only waste chemicals pose disposal problems. Hundreds of empty containers often litter locations where conventional treatments have been completed. To combat this, DS uses "tote tanks"—stainless steel, reusable tanks which meet US Department of Transport specifications for chemical transportation on highways. These are filled at the chemical plants and each one replaces six, disposable 55-gal drums.

At present, there are 400 tote tanks in the US, each expected to be used about six times a year. This will reduce the number of drums to be disposed of by 10,000—about a third of the quantity used annually.

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**Banishing Washboy Blues**

In less than a decade, programs have been introduced throughout the world to cut the toxicity of discharged waste. Legislation now being enforced is placing much greater emphasis on effluent treatment prior to disposal. To meet new standards, existing technology is being reconfigured and new treatment procedures devised.

Of prime concern for many oilfield operations is what happens to the waste streams from equipment washing facilities. During stimulation operations, equipment can be contaminated by chemicals used in the downhole treatment. Tools run into a well may be covered with drilling mud, formation fluids and contaminants such as pipe.
How the PCM Unit Mixes

The Precision Continuous Mixer is a self-contained, trailer-mounted unit that mixes gelled fracture fluid on the fly. To create the basic fracture fluid, potassium chloride (KCl) and polymer slurry gel (dry polymer dispersed in diesel) are combined with water. Time is needed for the polymer to hydrate. In the PCM unit, this process takes place in two interconnected “hydration tanks” with a combined capacity of 250 barrels (40 cubic meters (m³)). This capacity, combined with high shear mixers and controlled flow through the system, allows continuous mixing of up to 70 barrels/minute (11 m³/min). After hydration, the PCM adds metered quantities of liquid chemicals from four, 345-gallon (1,310-liter) tanks. This happens as the final mixture is pumped to the blender where sand is added.

All rates are monitored and displayed at the PCM console which offers computer and manual control. Flow information, along with pH, temperature, conductivity and viscosity, are measured and transmitted to the Treatment Control Vehicle (TCV®), the control point for all mixing, blending and pumping hardware.

Typically fracture jobs require large volumes of KCl, so it is not transported in the PCM but is carried in tankers to the wellsite, stored on location in frac tanks and taken onboard through two 4-inch (10-cm) openings.

Slurry gel is mixed at the service base by adding conventional gelling polymers to diesel. Up to 1,500 gallons (5,700 liters) of the slurry can be transported in the PCM system. The slurry storage tank is split into two sections that can be circulated to ensure the gel slurry remains evenly dispersed in the diesel.

The slurry is metered and added to KCI and water to form a uniformly hydrated, viscous fracturing fluid without lumps, called fish-eyes. The maximum output from the PCM equipment for a specified level of hydration depends on the water injection rate which affects the hydration kinetics (above, right). To ensure uniform hydration of the gel, the two hydration tanks are split by a series of baffles into six compartments. Mixers in four of the compartments provide a high-shear environment to speed the hydration process. Without the baffles and mixers, flow would bypass portions of the tanks, decreasing effective tank volume and the level of hydration achieved (below).

Water, gel and KCI are pumped into the first compartment of the first tank. This mixture then works its way over and under the baffles, hydrating as it goes, until it reaches the sixth compartment. The mixers in the middle four compartments increase the hydration rate and eliminate dead spaces.

A centrifugal pump provides high-shear mixing to complete hydration by recirculating the fluid in the fifth and sixth compartments. This also maintains a constant hydraulic head in the final compartment for the blender.
dope containing heavy metals like chromium, zinc and lead. During equipment cleaning, water picks up these contaminants. Cleaning this water runs the gamut of complexity, from relatively simple solids removal to the complex elimination of organic compounds.

In general, specifications of most washbays are falling behind today's tightening standards. Future regulatory demands for pollution control are likely to become even stricter. To meet these demands, Dowell Schlumberger in Tulsa, Oklahoma, USA, has designed a series of washbay modules which, when combined, form washbays with progressively increasing treatment capability. The first system is expected to be operational by the end of 1990 (right). Anadroll, meanwhile, is concluding a yearlong pilot scheme of a 500-gallon per day [1.9-cubic meter per day] wastewater treatment system in Lafayette, Louisiana, USA.

Both developments follow broadly similar lines: water plus waste is trapped in a sump, solids are removed then oil skimmed and, if necessary, further organics adsorbed. The DS design is flexible—throughput and exact configuration depend on location. The modules are designed to fit together like building blocks to treat a diverse range of chemicals. This flexibility will meet differing regulations and the need to upgrade equipment in response to new chemicals. The washbay modules are combined to address four categories of waste purity:

- Category I—removal of suspended solids and oil only
- Category II—a higher level of treatment prior to discharge, without recycling the waste water
- Category III—a treatment to meet yet stricter discharge requirements or recycling
- Category IV—for locations with special needs like neutralization or removal of metals and special chemicals.

Category I requires three main modules: a washbay area, collection-ump/lift-station and solids separation unit. These and all other modules are sited above ground, allowing inspection and avoiding secondary environmental problems like undetected leaks, which can arise with underground systems.

The washbay is a concrete slab with 2-foot [60-centimeter] high curbing around the sides for containment. Concrete block walls about 8 feet [2.5 meters] tall around the bay will contain splashing during washing operations. To collect all waste, the slab slopes into the center with an overall gradient from front to rear, and drains into a 60-gallon [228-liter] collection sump.

The sump is a 4-foot [1.2-meter] diameter vessel inside a poured concrete basin with lift eyes for easy removal to allow cleaning, inspection and maintenance. A removable wire mesh basket catches large pieces of debris and the remaining solids are ground smaller by a float-activated pump. This makes the effluent easier to pump to the solids separation unit—a high-speed, centrifugal separator followed by a slow sedimentation tank.

The centrifuge removes solids with a specific gravity greater than 1.1 and a diameter greater than 74 microns (μm). Effluent is then transferred to an above-ground sedimentation tank. This partitioned upflow/downflow settling chamber offers up to three hours residence time to allow gravity separation of any remaining undissolved materials. The collected solids can be dried and, in most cases, disposed of in a commercial landfill as nonhazardous waste.

If a separate oil phase floats to the surface, it can be removed with a skimmer for recycling or disposal. Chemical flocculants or pH adjustments may be required to improve sedimentation, more efficiently remove metals or prepare the fluid for additional treatment steps. Local conditions may allow discharge of the aqueous effluent from this system into a sewer.

For category II a number of different options are assessed: either a biological treatment module or mechanical separators are most likely to be selected. The bio unit receives effluent from the sedimentation tank and produces a high-quality effluent stream that usually allows discharge into a public sewer. The unit includes an aeration chamber for air purging, a clarifier for solids separation and a sludge holding tank to collect residue which is not further biodegradable. Air is bubbled through the waste to sustain aerobic bacterial activity that biodegrades organics such as petroleum hydrocarbons, toluene, xylenes and ethylbenzene, converting them to gases (mostly carbon dioxide) and additional bacteria. At the same time, the air strips the by-product gases to the atmosphere. The cell mass is removed by sedimentation in the clarifier and is later
decanted, dried and disposed as nonhazardous waste.

Bubbling air through the waste also strips out volatile organic compounds such as 1,1,1 trichloroethane. At present, air plus organics can be vented to the atmosphere, although this may be restricted in the future. Compounds with high vapor pressures or a resistance to biodegradation may not be removed by this module. In that case, carbon adsorption has to be used downstream.

Mechanical separation would involve tilted coalescing plates which help remove oil from the waste.

Category III requires further modules to perform chlorination for disinfection and filtration/recirculation using multimedia backwashable filters, storage tank and recirculation pumps. The filters remove particles over 25 μm—a standard accepted by the water industry. The output from this system is high-quality water, free from suspended solids, which may be recycled to the washbay system or used for nonpotable purposes.

Finally, for Category IV, additional modules have been designed to meet particular needs of field locations. Unlike the previous modules that are configured sequentially, Category IV hardware may be located throughout the cleaning sequence.

A common additional requirement is for acid neutralization. For hydrochloric acid (HCl), this involves a simple procedure of mixing and circulating a caustic solution and a method for monitoring and controlling pH. Disposal of the neutralized solution, however, is more complex and must take into account not only neutralization by-products, but also the chemical additives present in the original acid solution. If flocculation or pH buffering is needed, effluent from this neutralization can be injected upstream of the separation unit. Otherwise, the effluent can be introduced upstream of the bio-chamber for treatment of organics.

Treatment of hydrofluoric acid (HF) is more difficult. Neutralization requires the introduction of lime and calcium chloride. This precipitates fluoride as calcium fluoride which can then be removed in the slow sedimentation tank. Alternatively, fluoride can be removed by a reverse osmosis unit, if inclusion of this module has been justified by other requirements. Carbon filters—to adsorb persistent organic compounds or chemical additives—and special solids removal equipment complete the Category IV options.

While Dowell Schlumberger finalizes module design, Anadrill is concluding its pilot scheme for wastewater treatment. Following assessment of the field trial, Anadrill hopes to produce a blueprint for all its locations. This system recycles the water for reuse in the washbay steam cleaners rather than dumping it in the sewers. Once in the sump, waste is filtered to remove heavy metals and lifted into an aeration tower using an explosion-proof pump, a safeguard against flammable waste. In the aeration tower, air bubbles mix with the water and enhance separation. Use of soaps or surfactants has been discouraged because these tend to suspend oil in the water and inhibit gravity separation.

From the separation tank, contaminated water travels up through inclined coalescing plates. Simultaneously, the solids settle. Oil accumulated on the surface of the tank is collected by a brush wheel and stored for later disposal. The water and remaining contaminants continue through a gravity separator, hydrocarbon adsorber, centrifuge, chlorinator and a final filtering phase which removes solids down to 20 μm. After this, the water can be reused while solids are returned to the collecting sump which is emptied at around 75 day intervals. —CF
dope containing heavy metals like chromium, zinc and lead. During equipment cleaning, water picks up these contaminants. Cleaning this water runs the gamut of complexity, from relatively simple solids removal to the complete elimination of organic compounds.

In general, specifications of most washbays are falling behind today’s tightening standards. Future regulatory demands for pollution control are likely to become even stricter. To meet these demands, Dowell Schlumberger in Tulsa, Oklahoma, USA, has designed a series of washbay modules which, when combined, form washbay systems with progressively increasing treatment capability. The first system is expected to be operational by the end of 1990 (right). Another, meanwhile, is concluding a year-long pilot scheme of a 2.0 million gallon per day (79-cubic meter per day) wastewater treatment system in Lafayette, Louisiana, USA.

Both developments follow broadly similar lines: water plus waste is trapped in a sump, solids are removed then oil skimmed and, if necessary, further organics adsorbed. The I/S design is flexible—throughout and exact configuration depend on location. The modules are designed to fit together like building blocks to treat a diverse range of chemicals. This flexibility will meet differing regulations and the need to upgrade equipment in response to new chemicals. The washbay modules are modular to address four categories of waste purity: Category I—removal of suspended solids and water; Category II—a higher level of treatment prior to discharge, without recycling the wastewater; Category III—a treatment to meet stricter discharge requirements or recycling; Category IV—special needs like neutralization or removal of metals and special chemicals.

Category I requires three main modules: a washbay area, collection-sump/filtation and solids separation unit. These and all other modules are set above ground, allowing inspection and avoiding secondary environmental problems like undetected leaks, which can arise with underground systems. The washbay is a concrete slab with 2-foot (60-centimeter) high curbing around the sides for containment. Concrete blocks about 8 feet (2.5 meters) tall around the bay will contain washing during washing operations. To collect all wastewater, the slab slopes into the center with an overall gradient from front to rear, and drains into a 60-gallon (228-liter) collection sump.

The sump is a 4-foot (1.2-meter) diameter vessel inside a poured concrete basin with lift eyes for easy removal to allow cleaning, inspection and maintenance. A removable wire mesh basket catches large pieces of debris and the remaining solids are ground smaller by a float-activated pump. This makes the efficient easier to pump to the solids separation unit—a high-speed, centrifugal separator followed by a slow sedimentation tank. The centrifuge removes solids with a specific gravity greater than 1.1 and a diameter greater than 27 microns (μm). Effluent is then transferred to an above-ground sedimentation tank. This partitioned up-flow/down-flow settling chamber offers up to three hours residence time to allow gravity separation of any remaining undissolved materials. The collected solids can be disposed of, and in most cases, disposed of in a commercial landfill as nonhazardous waste.

If a separate oil phase flows to the surface, it can be removed with a skimmer for recycling or disposal. Chemical flocculants or pH adjustments may be required to improve sedimentation, more efficiently remove metals or prepare the fluid for additional treatment steps. Local conditions may allow discharge of the aqueous effluent from this system into a sewer.

For Category II, a number of different options are assessed: either a biological treatment module or mechanical separators are most likely to be selected. The bio unit receives effluent from the sedimentation tank and produces a high-quality effluent stream that usually allows discharge into a public sewer. The unit includes an aeration chamber for air purging, a clarifier for solids separation and a sludge holding tank to collect residue which is not further biodegradable. Air is bubbled through the waste to sustain aerobic bacterial activity that biodegrades organics such as petroleum hydrocarbons, toluene, xylene and ethylbenzene, converting them to gases (mostly carbon dioxide) and additional bacteria. At the same time, the air strips the by-product gases to the atmosphere. The cell mass is removed by sedimentation in the clarifier and is later

decanted, dried and disposed as nonhazardous waste. Bubbling air through the waste also strips out volatile organic compounds such as 1,1,1-trichloroethane. At present, airplus organics can be vented to the atmosphere; although this may be restricted in the future.

Compounds with high vapor pressures or a resistance to biodegradation may not be removed by this module. In that case, carbon adsorption has been used to downstream. Mechanical separation would involve tilted coalescing plates which help remove oil from the waste.

Category III requires further modules to perform chlorination for disinfection and filtration/recirculation using multimedia backwashable filters, storage tank and recirculation pumps. The filters remove particles over 25 μm—a standard accepted by the water industry. The output from this system is high-quality water, free from suspended solids, which may be recycled to the washbay system or used for nonpotable purposes.

Finally, for Category IV, additional modules have been designed to meet particular needs of field locations. Unlike the previous modules that are configured sequentially, Category IV hardware may be located throughout the cleaning sequence. A common additional requirement is for acid neutralization. For hydrochloric acid (HCl), this involves a simple procedure of mixing and circulating a caustic solution and a method for monitoring and controlling pH. Disposal of the neutralized solutions, however, is more complex and must take into account not only neutralization by-products, but also the chemical additites present in the original acid solution. If flocculation or pH buffering is needed, effluent from this neutralization can be injected upstream or the separation unit. Otherwise, the effluent can be introduced upstream of the bio-chamber for treatment of organics.

Treatment of hydrochloric acid (HCl) is more difficult. Neutralization requires the introduction of lime and calcium chloride. This precipitates fluoride as calcium fluoride which can then be removed in the slow sedimentation tank. Alternatively, fluoride can be removed by a reverse osmosis unit, if inclusion of this module has been justified by other requirements. Carbon filters—to adsorb persistent organic compounds or chemical additites—and special solids removal equipment complete the Category IV options.

While Dowell Schlumberger finalizes module design, Andrill is concluding its pilot scheme for wastewater treatment. Following assessment of the field trial, Andrill hopes to produce a blueprint for all its installations. This system recycles the water for use in the washbay system cleaners rather than dumping it in the sewers. Once in the sump, waste is filtered to remove heavy metals and lifted into an aeration tower using an explosion-proof pump, a safeguard against flammable waste. In the aeration tower, air bubbles mix with the water and enhance separation. Use of ropes or surfac- tants has been discouraged because these tend to suspend oil in the water and inhibit gravity separation.

From the separation tank, contaminated water travels up through inclined coalescing plates. Simultaneously, the solids settle. Oil accumulated on the surface of the tank is collected by a brush wheel and stored for later disposal. The water and remaining contaminants continue through a gravity separator, hydrocyclone chamber, centrifuge, clarifier and a final filtering phase which removes solids down to 20 μm. After this, the water can be reused while solids are returned to the collecting sump which is emptied at around 75 days intervals. —CF