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Abbreviations and acronyms used throughout articles include:
EPA Environmental Protection Agency
U.S. Underground Storage Tank
ppm parts per million
ppb parts per billion

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Soil in a day’s work

In the April 1995 issue of this magazine, an article appeared on page 24 about a new guide from the EPA titled, How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers. In my introduction I called it, “the best overview of soil remediation technologies...I have seen. It’s like the professor handing out the answers to the exam the day before the test!” According to Debby Tremblay, team leader for OUST’s Corrective Action Technology Team, the Guide has been expanded to add two new chapters or dual-phase extraction and in-situ groundwater bioremediation.

“According to state regulators, one of the most common barriers is the lack of technical guidance explaining how to review corrective action plans that propose alternative technologies,” says Tremblay. “Without such guidance, regulators are not confident of their review of plans proposing alternative technologies.” The Guide has been distributed to federal, state and local regulators to help them determine if an appropriate technology is proposed for a site, and it is a technically sound approach. Consultants and others can obtain a copy for $28 from the U.S. Government Printing Office by calling 202-512-1800, ask for stock number 055-000-00499-4.
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Letters

Your editorial on lawyers (April 1995, page 5) was a breath of fresh air. My only criticism is that you left out the adjectives “scum-sucking,” “limp-wristed,” and the noun “maggot.”

Very truly yours,
J. Ray Preston, P.E.
Macon, Ga.

By way of introduction I would like to state that I am not an attorney, but have some comments pertaining to your editorial in the April 1995 issue.

This editorial displays a very stale, overworked and overrehearsed concept of the legal profession. Certainly there are those who have “cashed in” on the “Superfund,” as there are those who “cash in” on personal injury cases, high profile criminal defense cases etc., but your unsupported characterization of an entire profession although typical, is very dangerous for an engineer, which I assume you are. I suppose you are unaware of any engineers, geologists or landmen who cashed in on the oil and gas boom of the early 80s. In fact, the most despicable people I have ever encountered in my life were engineers, geologists and landmen. I would also fault you for offering no solutions of your own to what you consider to be such a serious problem.

As a regulator I have had the good fortune to work with a few very dedicated, hard working, low paid state environmental attorneys. Blanket characterizations such as your betray the efforts of these dedicated people.

It is always generalizations such as yours which display the most pervasive ignorance of people like yourself and do the most harm to society. I would assume that if you are ever involved in an automobile accident with an uninsured driver you won’t be calling your butcher for help. It is so very easy to take really cheap shots at people from your lofty position as managing editor of a mediocre magazine, especially when you provide no opportunity for response, but then I seriously doubt that you have the courage to reprint this or any other responses you may have received regarding that half thought out editorial.

Sincerely,
Lewis Donlon II
Louisiana Dept. Environmental Quality
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Write in 336
During early July, GeoClean Inc., of Waukesha, Wisc., began the initial shakedown of their new Enviro-Tech™ thermal desorption system, manufactured by CMI Corp., Oklahoma City.

The plant has been set up in Madison, Wisc., for its first project, and will move shortly to another site in Wisconsin. The plant is a convertible system which allows it to be set up in two different configurations. The “A” mode is for soils with lighter end hydrocarbon contaminants and the “C” mode handles heavier fractions.

GeoClean needed a system that could move well so they could bid large projects having low to mid temperature treatment requirements up to 450°C. They also needed a system to handle the heavy end hydrocarbon contaminated material, able to reach temperatures as high as 650°C. The combination system can process up to 144 metric tons per hour in the “A” mode, and up to 108 metric tons per hour in the “C” mode.

“We needed the high capacity throughput rates of the Enviro-Tech plant, but also realized that the system had to have mid-range temperature as well as high range temperature capability to address the entire remediation market,” explains Steve Handley, project manager of GeoClean. “We didn’t want to be restricted as to what jobs we could bid and what economics were involved,” he adds.

According to GeoClean vice president, Tony Bodway, the flexibility of the convertible plant makes sound economic sense and gives them the versatility to meet
customer's needs. "After the plant moves from the Madison site in the "C" mode, we're setting it up in the "A" mode for our next job. We simply park the "C" components and mobilize the "A" components," Bodway says.

"The soil type and contaminant types and levels restricted our production at this site to about 72 metric tons per hour. We should be able to kick into high gear at our next project site. We are eager to see this plant at full process capacity," Bodway says.

The simple plant view layouts of the two mode configurations are shown in figure one, above and on page 10. The base plant uses many of the same major parts in either mode—feeders, desorber, baghouse, cooler, controls and the power plant. The main difference between the "A" and the "C" mode is that the "C" mode places the thermal oxidizer before the fabric filter baghouse. This requires use of a high efficiency cyclone for dust removal and large air-to-air heat exchangers to condition the airstream for baghouse temperature entry levels.

Gaseous hydrocarbon molecules from heavy fuels

California dreamin'

California has the reputation for being one of the most stringent states for permitting for environmental cleanup. Remco, of Richmond, Calif., spent three years perfecting its permits in one of the toughest regulatory climates in the country, the San Francisco Bay Area. The lead agency, the Bay Area Air Quality Management District "exacts particulate standards 400 percent higher for thermal desorption than for comparable industries, such as asphalt plants, which are allowed to aerate emissions to the atmosphere" explains David Child, president of the company. Remco, however, was required to produce zero fugitive emissions, so they designed a 27 by 30 meter negative air enclosure to unload petroleum contaminated soils. This negative air system changes out the entire volume of air in the building twice each hour, and purges it through a carbon filtering system to prevent volatile gases from escaping to the atmosphere. "The regulatory agencies continually gave us conflicting guidelines," Child says. "We actually petitioned one agency for over two years to come to our site and give us guidelines for permitting. But they consistently told us that no permit was required. Only after a huge investment in our facility did a group from this agency show up to state that there was now an emergency because they had not permitted us!"

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Write in 484
Convertible plant, from page 9
condense at higher temperatures than those found in lighter fuels. The “C” mode therefore places the thermal oxidizer ahead of the fabric filter baghouse, eliminating these hydrocarbons before they have a chance to condense in the fabric filter baghouse.

System “A” uses P-84 Nomex bags in the fabric filter baghouse, limiting exhaust gas temperatures to 260°C or less at the baghouse inlet. System “A” lends itself to high capacity remediation of gasoline, diesel fuel, hydraulic oil and jet fuel contaminated soils. Heavy end hydrocarbons can be processed, but production capacity declines in proportion to the nature and quantities of the contaminants. Heavy end hydrocarbons also require longer dwell times in desorber and higher temperature burn levels, which lower output capacity.

The System “C” uses air-to-air heat exchangers which permit operation with high temperature exit gases from desorber and afterburner prior to baghouse particulate filtration. The vaporized hydrocarbon, particulate laden airstream leaves the desorber at around 425°C, and passes through the cyclone dust collector for 99 percent particulate removal. Gases enter the thermal oxidizer for hydrocarbon vapor destruction prior to entering primary and secondary air-to-air head exchangers. The primary stainless steel exchanger receives 870°C gas stream from the afterburner and reduces the temperature to around 450°C for entry into the fabric filter baghouse and final particulate removal. System “C” is designed for high temperature, heavy hydrocarbon processing, and although it requires additional components, it is offered in both mobile and stationary designs.

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10 August-September 1995 Soil & Groundwater Cleanup
Superfund: Let's get it right this time
Ten point plan to fix 15 years of bad law

By Richard Mahoney

Most observers would agree that the current Superfund law is among the most poorly crafted and counter-productive statutes of recent years. Because of its perverse and conflicting incentives, parties are inclined to litigate and delay rather than clean up. This has been the case throughout its history.

However, the law and its follow-on regulations, which have led to estimated expenditures through FY 1994 of about $28 billion (not including corporate legal costs) have not been a total waste. While the price per site cleanup has been exorbitant—at least something got done! That something includes:

- At 293 Superfund sites, according to EPA's assessment, the cleanup process is complete, and more than half the remaining sites are moving along in the process. EPA is targeting 650 completions by 2000. Unfortunately, the approximately 1,300 Superfund National Priority List (NPL) sites are potentially only the beginning. There are still some 19,000 sites that have had a preliminary EPA assessment that indicates they “appear serious” and need a site inspection to determine if they should be officially placed on the Superfund List. Thus, one cannot be complacent about the progress of cleaning up the current NPL sites.
- Nearly 4,000 Emergency Removal procedures have been carried out at NPL listed sites, and many more sites not yet officially on the List. Emergency Removal, as defined in the Superfund statute, is designed to remove and provide remedial action for “any pollutant contamination which may present an imminent and substantial danger to the public health or welfare.” In theory, therefore, at least by this definition, the “imminent and substantial danger to the public” is largely past. Some would argue, then, that—to paraphrase Senator Carl Aiken's advice on the Vietnam War—“It’s time for Superfund to declare victory and go home.” They cite the origin of Superfund which came in the aftermath of the Love Canal episode in the 1970s. At the outset, the intent was limited to removing hazardous waste. The expanded purposes of returning the site to “pre-disposal conditions” came later in the enlargement of the legislative debate. Many however—particularly site neighbors—would dispute the idea that the risk has passed, and others would further argue that environmental repair remains largely to be done.
- Hazardous waste disposal practices have been dramatically changed. For most companies, it would be inconceivable that the old practices would return. Continuing “retribution” may be needed to prevent some from slipping back—but the consequences of improper disposal are now clear to all, and the Resource Conservation & Recovery Act (RCRA) provides future deterrent incentives.
- In an ironic way, the horrors of the Superfund process and its incredible cost for limited cleanup have been a rallying point around which all participants can coalesce. Indeed, the Superfund Commission, in 1993-94, brought the various constituencies together to hammer out compromise legislation which unfortunately failed passage in the contentious closing days of the 103rd Congress.

The constant debate over

CONTINUES ON PAGE 12→

Richard Mahoney is distinguished executive in residence at the Center for the Study of American Business at Washington University in St. Louis, Mo. He is also chairman of the executive committee at Monsanto Co., where he served as CEO for 12 years. He served on the National Superfund Commission in 1993-94. The opinions expressed in this article are those of the author and do not necessarily reflect the views of the Center or Washington University.
Superfund, from page 11

Superfund over the years has resulted in some principles for which there is the basis for general agreement—wit admittedly a good deal of give and take needed in the details of the principles. Among the points of agreement are:

- Cleanup standards should meet the intended end use. An industrial warehouse and a playground need very different remedy approaches, and costs could be reduced dramatically with suitable remedy selection.
- The community should be involved as a full partner in all important site decisions and should have access to resources to enable that participation.
- There should be a “de minimis” standard. That is, parties that had only peripheral involvement or had only a very minor part in the Superfund site should have a corresponding limited liability. As soon as the overall law is repaired, they should be dealt with promptly and released. Major industrial participants want these de minimis parties released only as part of comprehensive Superfund reform for fear that otherwise, the impetus for needed changes might evaporate.
- Joint and several liability should be abolished in favor of proportionate liability. That is, a party should be responsible only for its own contribution to the site. Any unallocatable, “orphan shares” should come from the Superfund pool. Not all groups agree on this, however, a sort of grudging acceptance has evolved because this one provision has caused both enormous process costs and slows down progress as parties seek to limit their total liability.
- Properly engineered containment of the site is a legitimate, temporary remedy. In many cases, such as preparing the site for a future industrial warehouse, containment may be an appropriate, permanent remedy. The fact of the matter is that there simply are no currently available, generally accepted, cost-effective procedures for complete restoration of most sites. Until cost-effective and neighbor-friendly solutions are developed, properly executed containment wins by default for most sites. However, Superfund money should be set aside for research to cost-effective solutions acceptable to the community where cleanup to standards higher than industrial use is appropriate.
- Despite the multi-year EPA Emergency Removal program, if there are any sites still remaining
which have obvious hazards—like leaking containers or pools of hazardous materials or removable hot spots that might migrate into groundwater or surface water, they should be handled on an emergency basis. This is not a long list, but it is a substantial area of potential agreement. One can make an additional list of areas where some tradeoffs among interested parties might produce further agreement. This would include:

- Limitation of new sites to the Superfund NPL. Many argue that after 15 years, with all the public awareness, if a site has not made it onto the Superfund NPL, its addition should be strongly challenged. The threshold numerical rating for inclusion on the NPL is highly arbitrary and does not necessarily separate hazardous sites from non-hazardous.
- After Emergency Removal is complete, many more sites can be delegated to the states, along with Superfund pool funding, to let local officials decide the best course of action, using guidelines, but not prescriptions from EPA.
- Current funding procedures

Superfund XVI to focus on hazardous waste remediation

Sen. Bob Smith (R-N.H.) and Andrew Young, vice chair of Law Companies Group, will join Thomas Grumblly as featured speakers at the opening plenary session of Superfund XVI, to be held Nov. 6-8, 1995 in Washington DC. Grumblly is assistant secretary for environmental management for the U.S. Department of Energy. EPA administrator Carol Brower is also an invited speaker. Newt Gingrich, speaker of the House, is invited to speak at the Environment 2000-New Directions in Environmental Policy conference to be held in conjunction with Superfund XVI. The conference is expected to attract 7,000 industry vendors, buyers and innovators at the Sheraton Hotel in Washington DC. The conference will feature its international "Going Global" segment. The EPA will present its annual conference track which will examine Brownfields Initiatives, Superfund Reauthorization and environmental justice initiatives. The conference is sponsored by Hazardous Materials Control Resources (HMCRI) and organized by E.J. Krause and Associates Inc., Washington DC. HMCRI is a non-profit organization. For information, contact Susan Newman at 301-986-7800.

Continues on page 14→
Superfund, from page 13

should be re-examined. Large amounts of available Superfund monies are not currently being spent and, in effect, they are “taxation for deficit reduction.”

- The existing or reformed Superfund program should come to an end—perhaps in 10 years, at the outside.

Beyond the agreed principles, and others that might yet find agreement, there are two major issues that appear to defy solution, and are the most contentious impediments to complete overhaul of the system:

- Elimination of retroactive liability for then-legal disposal acts occurring before the December 31, 1980 effective date of Superfund, or before its reauthorization date of December 31, 1986. Potentially responsible parties (PRPs) argue that the current statute is unfair, since much of the disposal was legal at the time it was done. Proponents of retaining retroactive liability argue that the polluter pays principle is inviolate and an important future deterrent.

If retroactive liability were to be eliminated, then establishing which materials in many sites were placed there prior to the date liability is established, and which came later would open the same process loss litigation problems which currently plague this program. A further complication is that, if retroactivity is to be removed, no one has yet determined who will clean up these pre-1980 or 1986 sites, and where the money will come from. Glib statements like “a new agency” or “the Corps of Engineers” or “the states,” and “existing or new funds” all defy specificity.

- The relationship between the insurers and their insureds for Superfund liability is not an appropriate subject for Congress. so far, courts have held almost equally for both. It seems highly unlikely that Congress could craft an equitable solution that the courts have failed to reach after years of litigation. One could argue that this is a contractual matter between insurers and insureds.

I propose that Superfund Reauthorization proceed along these ten points:

1. Retroactive liability should be retained as in the current law. This issue has so many difficult aspects that it virtually defies resolution. However, to provide fairness, partial compensatory offsets are made for PRPs under point 6, below.

2. Insurance issues would be left to settlement by the parties involved. To include insurance resolution in Superfund reauthorization is certain gridlock. With the containment process described in point 4, below, future costs and liabilities can be more predictable, and settlement between insurers and insureds more feasible compared to the current open-ended liability situation.
3. Joint and several liability would be replaced by proportionate liability with Superfund paying for orphan shares.

4. The highest priority is to complete the Emergency Removal process at all NPL sites and a select number of major sites awaiting NPL listing. Emergency Removal would be limited to leaking or otherwise damagable containers, to highly concentrated areas of hazardous materials, and to plumes from the site. A time limit should be established for Emergency Removal program completion—perhaps three years.

5. No new additions should be made to the NPL during the life of the Emergency Removal program except for obvious sites of extraordinary hazard.

6. NPL sites and a certain number of priority sites not currently on the NPL should be capped arbitrarily at about 100 to 200 new sites, and would be divided into two categories:
   • For sites where properly designed containment is a satisfactory permanent remedy, such as sites restricted to future industrial uses, PRPs will complete the work—with the Fund if needed for orphan shares. An amount—for example 10 percent of actual construction costs of containment—would be placed in escrow by the funding parties. This is a monitoring and maintenance fund. At that point, with containment complete, and escrow funds in place, PRPs are relieved of all future liability. This liability relief is a critical part of the tradeoff to PRPs for retaining retroactive liability.
   • Sites for which future use is unknown would also receive containment procedures and a maintenance escrow fee. In addition, an amount equal to the maintenance escrow would also be escrowed for future remediation should suitable technology become available and the community choose to use it. If remediation to a higher-than-industrial quality standard is selected, the state or appropriate local body would be required to match the Superfund share of the remediation escrow. If after a period of, for example, 10 years, the site is still unused, the amount escrowed for remediation would be returned to the PRPs. These incentives are all aimed at encouraging industrial or other restricted use. In the overwhelming number of cases, it makes sense to do so to avoid the possibility of “Love Canal-like” behavior where a site is developed for a school or for residential use. In any case, for illustration purposes, the total surface area of Superfund sites (excluding military and national laboratory sites) can be very roughly estimated at about 20,000 hectares—about the size of a half-dozen large wheat farms. While this is not a trivial amount, the contentious history and potential future problems argue that it is best used for industrial purposes or contained and left unused. There might be clearly cost-effective, full remediation procedures now available for a limited number of sites. If so, they should be remediated rather than contained. Based on Superfund experience to date, however, these are few indeed—otherwise cleanup would have already been completed.

   In sites not yet well underway in construction, but where a non-containment remedy has been directed, the EPA-proposed remedy should be challenged for cost effectiveness against the containment alternative. This is necessary since many remedies are directed with grossly inadequate support for their choice. For all sites, an independent Superfund Trust would be established to hold the escrow account and disperse it as needed, as well as to assist in determining

Continue on page 16→
Superfund, from page 15

future sites use. These funds would be kept separate from general federal use or local access except through the Trust. Public policy will dictate whether to have one National Trust for all sites or individual local ones. Local administration appears to be a better choice. Models for the Trust concept exist in current EPA containment sites. PRPs may or may not choose to participate as Trust members.

7. A substantial amount of Superfund money ($50 to $100 million per year) should be allocated to peer-reviewed, competitive research proposals to develop cost-effective, neighbor-friendly permanent remediation. These funds, plus the remediation escrow and potential land value increases, should be adequate incentives for research and development efforts to be undertaken by the private sector.

8. Communities should be empowered and funded for full participation in the Superfund Trust, the remedy selection and the completion process. However, the procedures in points 1 to 6 above should govern overall.

9. After satisfactory reauthorization of Superfund, de minimis participants should be relieved from all future liability upon payment of a nominal share. The terms “de minimis” and “nominal” still need to be defined, but the intent of the definition should be to relieve those who made very small contributions to the site, such as the casual small business participants in municipal sites. Municipal operators themselves would remain subject to PRP procedures. Banks and other casual, non-disposal participants would be relieved of liability. Contractors doing containment or remediation would be relieved of future environmental liability upon acceptance of the site by the Trust.

10. Minority and/or poor communities would receive preferential priority in the resolution processes described above to ensure that they receive recognition for any past “second class” treatment by Superfund. These ten points represent an outline for Superfund reform. They provide a basis for tradeoffs among the parties’ interests, incentives for directing solutions and, most of all, a hope that within the next five to 10 years, the U.S. can accomplish the original purpose of Superfund—to remove the hazards of decades of waste practices that are unacceptable by today’s standards, and inappropriate to an enlightened society.
Bioreactor cleans up Canada
Performance results point to a better way

By D.M. McNicoll, A.S. Baweja, M.J.L. Robin, C.W. Greer and F. D’Addario

In December 1993, this magazine ran an article about remediation at Canadian Forces Base (CFB) Petawawa, located about 200 km northwest of Ottawa, Ontario. (See, “Bioreactor System Tests Temperature, Nutrients” December 1993 Soils, page 36.)

The Canadian Department of National Defence, in collaboration with Environment Canada and the firm of Oliver, Mangione, McCalla & Associates Ltd., designed and built an innovative aboveground bioremediation system consisting of four bioreactors in which conditions could be optimized to enhance natural degradation of the petroleum contaminants in the soil. They were especially interested to determine whether petroleum degradation is primarily the result of biodegradation or volatilization. Now, the results of the project are in, and here is what happened.

Total Petroleum Hydrocarbon (TPH) concentrations obtained from each soil sampling event for all four cells are shown in figure one, page 18. Each point on the graph is the mean of all measurements for a given cell and sampling session. It is apparent that a substantial reduction in TPH concentrations occurred in all four cells. The variability and concentration level in TPH measurements decreased drastically over time with variance measurements of approximately 20,000 ppm at early times—May to August 1993, to 260 ppm at later times—August to November 1993. The homogenization of the contaminant distribution is believed to be a combination of leaching effects from the moisture supply system and biological activity.

The amount of petroleum reduction observed in each of the four cells was calculated using the initial and final mean soil TPH concentrations for each cell. Based on these results, the percent reduction in TPH was calculated to be approximately 97 percent for cell A, 97 percent for cell B, 94 percent for cell C and 98 percent for cell D. This works out to be an average petroleum reduction of approximately 97 percent over all four cells.

The soil in all four bioreactors was found to have final TPH concentrations well below the most stringent federal and provincial criteria of 40 ppm, as demonstrated by the mean soil TPH concentration obtained during the final month of monitoring.

A microbiological program was undertaken to monitor biological activity within the cells. The purpose of this program was to collect evidence to demonstrate that biological degradation was, in fact, occurring within the cells. The program involved monthly enumeration of total viable bacteria (non-selective, medium), hydrocarbon-degrading viable

Continues on page 18+

Background of the test
Canadian Forces Base Petawawa is a Major Mobile Command Base with a bulk petroleum storage facility, and over 1,000 cubic meters of petroleum and diesel contaminated soil—up to 12,620 ppm in some spots. An engineered aboveground bioreactor system was installed in the fall of 1992, consisting of four identical bioreactors, each approximately 26 meters long and 14 meters wide. Each cell was built up to a height of about two meters and contains approximately 360 cubic meters of soil. Nutrient delivery systems, geomembrane liners and drainage systems were installed as in the illustration above.

Dan McNicoll is contaminant hydrogeologist with Oliver, Mangione, McCalla & Associates Ltd., Nepean, Ontario; Anar Baweja and Frank D’Addario are senior environmental officers with Environment Canada, Nepean, Ontario; Michel Robin is hydrogeologist with the Ottawa-Carleton Geoscience Centre, Ottawa; C.W. Greer is with the Biotechnology Research Institute, National Research Council, Montreal, Quebec.
bacteria (diesel, gasoline medium), determination of bacteria with the genetic potential to degrade aromatic hydrocarbons (xyle probe-positive) or short chain aliphatic hydrocarbons (alkB probe-positive), and determination of the initial mineralization activity in the soils using labelled toluene and hexadecane as test substrates.

The viable population of hydrocarbon degrading bacteria, as determined on diesel, gasoline medium, was as large or larger than the population of viable bacteria recovered on low nutrient, non-selective (yeast extract-tryptone-starch) medium—as in figure two, above. Increases in bacterial numbers in both cases closely paralleled the increase in soil temperature, which peaked between July and August. The results indicate that the viable bacteria are either quite resistant to any potential toxic effects of the gasoline and diesel products, and/or that they are able to degrade these compounds—both desirable in a bioremediation project.

Bacteria that were positive for both the askB and xyle gene probes also increased in number paralleling soil temperature increases. Similarly, mineralization activity by the indigenous soil bacteria closely followed the temperature profile. The highest initial mineralization rates were obtained between July and August when the soil temperatures reached a maximum.

These results demonstrate that hydrocarbon-degrading bacteria were present in the soil, their numbers represented a substantial percentage of the total viable bacteria recovered, that they were actively degrading the types of hydrocarbons present in the contaminated soil, and their activity was closely
related to soil temperature.

In situ soil vapor oxygen and CO$_2$ concentrations were measured in each of the four cells biweekly during the six month monitoring period. The results are shown in figure three, above. In general, the mineralization of petroleum hydrocarbons can be expressed as:

$$\text{Hydrocarbon} + O^2 \rightarrow H_2O + CO_2 + \text{biomass}$$

In this reaction, the mineralization of hydrocarbons results in oxygen being consumed, and CO$_2$ being produced.

Based on the measured O$_2$ concentrations in figure three, aerobic conditions were maintained within each of the four cells throughout the six month monitoring program. Of interest is the O$_2$/CO$_2$ trend between days 200 and 210, when the soil vapor extraction system was temporarily shut down. During this period, soil oxygen concentrations in all four cells decreased and carbon dioxide concentrations increased. Once the vapor extraction system was reactivated, on day 210, the oxygen concentrations increased to their pre-shutdown levels, and a corresponding increase in CO$_2$ concentrations was observed. This trend is what one would expect to see in a situation where aerobic biodegradation of the hydrocarbon contaminants is occurring.

The amount of biodegradation that occurred during the project was determined by performing TPH mass balance calculations.

The total initial mass of TPH in the contaminated soil was calculated to be approximately 1,096 kg, while the remaining mass, at the end of the operating period, was approximately 30 kg—a reduction of approximately 1,066 kg, 97.4 percent.

Due to the self-contained nature of the bioreactor system, reduction in TPH mass within the soil could result from: leaching, volatilization and/or

Continues on page 20→
Bioreactor cleans up Canada, from page 19

mineralization or biodegradation. A summary of reduction of TPH mass from each of these processes is presented in figure four, above.

The mass of TPH that leached from the soil was determined through analysis of water samples collected at the base of each of the four cells at the end of the operating period. Although detectable TPH concentrations were measured in the water during the operation of the bioreactors, no detectable concentrations were measured in any of the four cells at the end of the project. The dissolved TPH concentrations measured in the leachate during the monitoring period may be a result of microbial-induced surfactants which solubilized adsorbed hydrocarbons at the onset of biostimulation. This phenomenon is often observed in bioremediation projects. TPH concentrations detected in the water during the operating period are believed to have been degraded within the soil as the water was recirculated through the bioreactors. For calculation purposes, TPH concentrations below the analytical detection limit were assumed to be one half of the detection limit. The corresponding mass of TPH that may have leached from the soil was calculated to be 0.002 kg for each cell, 0.008 kg total.

The amount of volatilization that occurred over the six month monitoring period was calculated using two methods. The first involved multiplying the petroleum hydrocarbon concentration measured within the soil vapor bi-weekly, by the average volume of vapors extracted from that cell over the same period. The mass of TPH that was volatilized from each cell was calculated by summing the bi-weekly volatilization losses over the six month operating period. The mass lost due to volatilization using this method was calculated to be approximately 4.7 kg, or 0.4 percent of the total TPH mass reduced.

The second method to estimate the amount of volatilization was simply to collect representative carbon samples from the central vapor treatment facility, and have them analyzed. The TPH concentration was multiplied by the total mass of carbon to obtain the total mass of TPH that was adsorbed to the carbon filters. The calculated TPH mass adsorbed to the carbon is considered to represent the mass which was volatilized from the soil. Using this method, the calculated mass of TPH that may have volatilized from the soil was approximately 0.9 kg, or 0.1 percent of the total reduced TPH mass.

The reduction in TPH mass that can be attributed to biological degradation processes was calculated by subtracting the sum of TPH mass lost due to leaching and volatilization from the total reduction in TPH mass—previously calculated to be 1.068 kg. The reduction in TPH mass that is attributable to biological degradation processes was calculated to be approximately 99 percent, or 5.6 kg per day over the operating period of the bioreactors.

As with any remediation project, the cost effectiveness must be scrutinized. The cost to design, construct and monitor this facility is estimated to be in the range of $70 to $90 per metric ton of treated soil. It is anticipated that these costs can be reduced to $20 to $40 per metric ton with continued re-use of the facility and a less stringent monitoring program.

This project demonstrated that enhanced biological degradation of diesel gasoline contaminated soil can be done in a typical Canadian summer. The results indicate that aboveground bioreactors are safe, cost effective and an environmentally benign method to remediate petroleum contaminated soils.

Oliver, Mangione, McCalla & Associates Ltd. is preparing to commercialize this process under the trade name A.M.O.E.B.A. (A Mechanically Oxidized and Enhanced Biodegradation) Process. Write in 796 for more information.
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**Cedarapids model 64, 100 and 114 kick gas**

Cedarapids, a Raytheon Company, in Cedar Rapids, Iowa makes a full line of thermal desorption systems to treat hydrocarbons. Models 64, 100 and 114 operate at soil discharge temperature of 190 to 530°C. All consist of: rotary kiln, baghouse, thermal oxidizer and reconstitution mixer. Plants can function as portable or stationary systems. They can treat most soil types, ranging from heavy silty clay to sand. The company also makes a Soil Pre-Conditioning unit to provide a steady flow of screened feed to the thermal unit.

Write in 803 for more information

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**Tarmac Super 7 finds a home in L.A.**

Tarmac Environmental Co. Inc., Kansas City, Mo., ships three new Super 7 thermal remediation plants for summer '95 startup. All plants are portable, and have options of high temperature kiln, fines recycling into the dryer, and oxidizer located before the baghouse to facilitate heavier contaminants, like bunker oil and tank bottoms. Pictured is the Los Angeles facility, set up inside a building which includes the plant with a packed tower after the baghouse to polish the air stream.

Write in 804 for more information

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**Andersen 2000 systems adapt to climate**

Andersen 2000 Inc., Peachtree City, Ga., offers thermal systems available in winterized configuration, and plants specifically designed to operate in high temperature desert environments. Systems with capacities up to 27 metric tons per hour are available in mobile designs. Systems can be fired with natural gas, oil or propane. Each unit uses a combination of direct contact heat transfer and steam stripping to reduce organic contamination levels to less than 100 ppm, says the company.

Write in 805 for more information
Stalite facility serves the east

Stalite Environmental, Salisbury, N.C. accepts petroleum contaminated soils by truck or rail from all over the Mid-Atlantic and Southeastern part of the country. The facility receives soil into its 16,000 metric ton capacity covered, pre-treatment area. Soils are crushed and screened to provide a uniform feed size. The kiln is 300 millimeters in diameter and 4000 millimeters long, and can accomplish a treatment rate of over 40 metric tons per hour with retention time of 30 minutes. Treatment temperatures range between 550 and 1260°C. The facility is equipped with a laboratory to confirm the types and amounts of petroleum contamination in incoming soils, and to test treated soils for compliance and recyclability. Generators receive a certificate of remediation, and relief from further liability for the soils. Write in 806 for more information.

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Soil & Groundwater Cleanup August-September 1995 23
Thermal Equipment Roundup

Hawaiian Remediation & Recycling, Oahu, Hawaii, uses an Astec/SPI Inc. portable LTLD plant, manufactured at SPI headquarters in Chattanooga, Tenn. The facility is designed to accept and treat soils contaminated with a variety of contaminants. The plant has treated soils, clays, corals and filter solids with initial contaminant concentrations up to 200,000 ppm. The plant has a custom feed system, and uses light reformate from a nearby refinery as fuel. The facility is owned by Rust Remedial Services.

Write in 807 for more information

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Plant remedies paradise

Arizona plant sports small footprint
This portable thermal treatment plant in Tucson, Ariz., was built by Astec/SPI Inc., Chattanooga, Tenn, and is owned and operated by Southwest Soil Remediation Inc. The plant was built with vertical components to minimize the footprint and provide the capability of higher afterburner temperatures. This arrangement provides flexibility for treating a variety of contaminants. The system includes a custom, oversize rotary drum to allow for refractory lining to be easily installed inside for higher temperature capability.

Write in 808 for more information

Plant travels to Superfund site
Four Seasons Environmental Services of Greensboro, N.C. mobilizes their Astec/SPI Inc. plant to a Superfund site in Illinois. This portable system is designed to separate the rotary drum from the burner flame, which allows the entire drum to shower soils without flame penetration into the drum, or impingement of flame on the soils. The system pre-heats all combustion air used by the burners with energy that would otherwise be wasted.

Write in 809 for more information
ETG acquires new thermal design

Marine Technologies Inc., develops an indirect heated thermal desorption technology which operates under a high vacuum and temperatures up to 480°C to desorb organic compounds from soils, sludges and debris. ETG Environmental Inc., of Blue Bell, Pa., has acquired MTI and the technology. “The system has been under development, and has been refined to its fourth generation design during the last several years, and applied at multiple sites,” explains Richard Crosby, president of MTI. The system, with internal heating and agitation is highly flexible, operates in a batch mode and can handle difficult hazardous waste compounds.

“The MTI unit is a very compact, mobile system which is unique due to the application of high vacuum and heat while simultaneously agitating and mixing waste material and exposing waste particles to obtain very effective desorption,” says Yei-Shong Shieh, senior vice president of ETG.

ETG co-developed the latest design of the system and is operating it at a refinery in Puerto Rico to process K048-K052 hazardous wastes. These wastes are initially dewatered and treated to meet BDAT standards. All lab results to date show non detectable for wastes. ETG operates a similar unit at Research Oil Co. in Ohio, says Ronald Bacska, president and CEO of ETG.

ETG has been developing a variety of thermal desorption technologies under the trade name Therm-O-Detox® including a continuous medium temperature paddle design. Write in 810 for more information
Clean Soil of Columbia, S.C. manufactures steam stripping soil remediation machines to clean soils contaminated with petroleum hydrocarbons. The Clean Soil network of 18 machines has cleaned over 200 projects, ranging from a few cubic meters, to over 3800. The machine uses patented technology and is the only unit available that offers steam stripping technology on mobile equipment for on site use. New emissions equipment has virtually eliminated air emissions from the process, says Bart Lehmann, principal of the company. Smaller systems can be completely housed on a 13.5 meter flatbed trailer, larger units on several trailers—all roadable with no road permits required. The machines are permitted in over 20 states, including California and New Jersey.

Write in 811 for more information

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Kal-Con unit features wobble feeder

Kalkaska Construction, Kalkaska, Mich., uses plants made by ADM of Huntertown, Ind., that feature a wobble feeder that will pass wet, sticky or clay materials without clogging. Wobbling action of rotating elliptical bars causes material to tumble forward, assuring separation of fines and uniform feed rate. The portable unit has a counter current rotary kiln, filter baghouse with compressed air pulsation to remove dust. An enclosed auger conveys the dust back to the rotary kiln discharge to return it to the hot, remediated soil.

Write in 812 for more information

Pet-Con stresses predictability

Pet-Con Soil Remediation Inc., of Spring Green, Wisc., operates a mobile plant that can operate at fixed base sites where petroleum contaminated soils are collected and stored, or on site, at the point where the contaminated soil is generated. Mobilization of the plant requires eight to 10 trailers, depending on the burner fuel selected.

Pet-Con claims that thermal treatment of petroleum contaminated soils offers more predictable results than other options. They can predict an accurate time frame for completion of the project, predictable results, and predictable costs, based on number of tons in the site. The unit maintains a consistent average production rate of 36 to 45 metric tons per hour, but can reach as high as 63 metric tons per hour.

Write in 813 for more information

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For more information, call the Advanced Environmental Systems technical support group at 800-220-5330

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Write in 323
**Thermal Equipment Roundup**

**E Products oxidizer cuts fuel costs**

E Products, St. Paul, Minn., announces a new generation of Venturi thermal oxidizers and ground flares that increase oxidation rates of a wider range of contaminants while cutting fuel costs by approximately 30 percent.

The Venturi burner optimizes the mixture of fuel, combustion air and fume stream, resulting in complete combustion, says the company. The fume stream can be introduced to the burner as either fuel or combustion air, depending on lower explosive limit concentrations.

Write in 814 for more information

**Purgo unveils new indirect fired plant**

Purgo Inc., of Richmond, Va., offers a new low oxygen atmosphere indirect heated thermal desorption portable unit for the delisting, minimization and remediation of hazardous and non-hazardous soils and sludges, such as PCBs, PAHs, pesticides, chlorinated solvents, coal tars, creosotes and other RCRA wastes.

Designed to desorb volatile and semi-volatile organics under low oxygen conditions at temperatures up to 650°C, this unit is capable of processing 18 metric tons per hour, says the company.

Write in 815 for more information

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Thermal plant sets east coast on fire
New facility wins permit to remediate 2,000 metric tons per day

Paul Bracegirdle is on fire about thermal remediation. "It's a long term solution that satisfies government regulations, absolves businesses of liabilities, minimizes expense and makes the best use of limited resources," he says.

Bracegirdle has taken that fire, and years of design and engineering experience to build a state-of-the-art, one-stop facility in Falls Township Pa., R3 Technologies, convenient to business and industry along the Washington-New York corridor. "We are permitted to thermally remediate 2,000 metric tons per day," says Bracegirdle, "more than any other plant on the east coast." Bracegirdle worked closely with Soil Purification Inc., an Astec company, of Chattanooga, Tenn., fabricators of the plant.

The facility thermally remediates, recycles and beneficially reuses non-hazardous residual waste materials such as petroleum contaminated soils and aggregates, and waste-to-energy residues.

One feature of the R3 site is storage of incoming contaminated products in a fully enclosed, 3,780 square meter building under negative air, which assures zero emissions and volatilization until the material can be run through the desorption plant. The building has separate stalls so there is no co-mingling of product, and each project is able to be monitored, tracked and treated specifically to suit individual client needs.

The facility is equipped with a lab to test incoming and outgoing material on site. Incoming soils are blended to reach a consistent particle size, and to obtain a homogenous moisture and contaminant content throughout the project. Rocks, metals and other debris are screened and crushed as part of the process.

The material is transferred to a rotary drum, where it is heated with a Lo NOx and Lo CO direct-fired burner up to 650°C, to drive off moisture and all light and heavy contaminants. Remediated material is discharged into a pugmill, where water is added for cooling and dust control.

Meanwhile, the exhaust from the drum, containing vaporized contaminants, water vapor and products of combustion, is transferred to exhaust gas units where it is treated through a cyclone and then converted to carbon dioxide and water vapor by high temperature oxidation, up to 980°C.

Hot gases are cooled by a water injection cooling unit. Any remaining particulate materials are filtered out through a fabric filter baghouse unit. A primary exhaust fan pushes the clean exhaust gases through the heat recovery units or directly into the atmosphere.

After it is cooled in the pugmill, thermally treated material is discharged from the pugmill onto a conveyor and transferred to a storage area for post-treatment analysis and inventory. R3 guarantees clean output with a certificate of destruction that absolves the client of liability. The clean output is suitable for use as fill, landfill cover and other materials.

The state-of-the-art plant can process in excess of 85 metric tons per hour.

Write in 797 for more information.
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Write in 333

August-September 1995 Soil & Groundwater Cleanup 33
German washing process pulls out contaminants in a fine slurry

Modular system treats organics, inorganics

By Elliott Goldberg
The Harbauer soil washing process has been practiced on a commercial scale in Europe for the past nine years. It is being used in three plants in Germany and has cleaned thousands of tons of soils contaminated with organics, metals and cyanides.

Now available in the U.S. through Lockwood Greene Engineers Inc., New York, N.Y., the soil washing system is a physical separation process which concentrates the
German washing process, from page 35

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Write in 328

contaminated soil to about 5 percent of its original volume. This is accomplished with equipment commonly used in the mining and mineral processing industries—reactors, classification screens, hydrocyclones, mineral jigs, fluidized bed sorting, flotation, dewatering screens and thickeners.

This volume reduction concentrates the contaminants, which are lodged on the fine particle fraction of the soil, which is produced as a concentrated paste slurry.

This concentrate is subsequently treated to remove or recover the contaminant. The process is designed so that the contaminants can be removed by three methods:

- Contaminants are physically separated during the washing process.
- Contaminants are dissolved in the wash water.
- Contaminants are removed from the soil particles by overcoming the specific binding forces, and are dispersed in the wash liquid as an
emulsion or suspension. Occasionally, a surface active agent or other chemicals may be added to assist in the transfer of contaminants from the surface of solid particles to the wash water.

Further treatment depends on the particular contaminants in the concentrate, such as volatile or heavy organics, inorganics such as cyanides, metals—and may consist of chemical treatment, chemical extraction, thermal vacuum treatment or biological treatment. Each cleaning process is tailored to the particular contaminants involved.

The process water used in the soil washing process must be treated and recycled. This is done by treating the contaminated process water by chemical oxidation, precipitation, flocculation, sedimentation, oil separation, dissolved air flocculation, removal of solids by filtration and activated carbon adsorption. The cleaned water is recycled and used in the process.

The Harbauer system uses staged mechanical agitation which separates clean fractions from the contaminated soils. The initial separation steps take place with dry materials, followed by several stages of wet soil separation. A two-stage blade washer unit is followed by a classification screen where gravel and stone fractions are separated, and finally, separation of a clean sand fraction.

A multi-stage hydrocyclone unit separates the smaller than 15 micron fines, which are concentrated by flocculation, sedimentation and thickening.

The dislodged contaminants are concentrated in the fine fraction at below 15 microns. This material is especially suitable for a biological or thermal treatment since it has a homogeneous texture and contaminant distribution. Or, there are other options for treatment of the residual products.

Inorganic pollutants, such as heavy metals, can be treated several ways. In some cases, they can be extracted by dissolving in dilute acid, then precipitated by treating with alkali or recovered from the acidic solution via liquid ion exchange.

In some cases, the concentrated sludge containing the heavy metal can be stabilized, solidified and sent to an appropriate landfill.

The technology has been proven on a commercial scale and has processed soils containing petroleum products, benzene, toluene, xylene, ethylbenzene, polychlorinated biphenyls, phenol, halogenated hydrocarbons, cyanides and heavy metals.

The system is based on a modular design in which each module is pre-piped and pre-wired for quick connection and assembly.

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Elliott Goldberg is director of environmental services for Lockwood Greene Engineers Inc., New York.

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Write in 261

Soil & Groundwater Cleanup August-September 1995 37
Secrets of Clay
Why is it the most stubborn and difficult soil type to clean up?

By Alfred Conklin, Ph.D.

Soil clay is important in any soil remediation effort because it is the soil component that has the highest chemical and physical activity. Chemically it has high sorption for water, organic compounds and cations. Physically, it tends to stick things together and slow the movement of air and water through soil. Both of these characteristics are related to the small size of clay crystals. A knowledge of the basic characteristics of soil clay gives one the tools necessary to handle contaminated soil and soil remediation effectively.

There are three kinds of clays. Clays found in rock are called primary minerals. In soil, primary minerals quickly decompose and form secondary minerals. These have a regular three-dimensional crystal structure and well-defined physical and chemical characteristics. These are the most important clays in temperate region soils. The last kind are the amorphous clays. These are the remains of intense weathering of secondary minerals, and are found primarily in tropical climates.

Since they are commonly found in temperate region soils, secondary minerals are the ones most often encountered in remediation activity.

All clays have high activity and a strong affinity for water, cations and organic matter. Clay is the soil fraction that holds these components most strongly. Clay may hold pollutants, keeping them from entering water systems. It will also slow or even prevent the movement of air and water through soil, making cleanup more difficult. The affinity of clay for organic matter is complex. Some organic compounds are strongly held, and some very weakly held.

There are three mechanisms by which clays hold water, cations and organic matter. One is a general absorption related to the high surface area. Another is cation exchange capacity. The third is unsatisfied bonds at the edges. Clay surfaces are either a little positive or a little negative, as in figure one, page 39. Thus, compounds that are either positive of negative can be attracted to the surface of clay minerals. Some clays also have permanent negative charges that are a result of isomorphous substitution. This negative charge attracts cations and produces part of a soils cation exchange capacity (CEC). At clay crystal edges, bonds are unsatisfied, that is, they are attached to only one atom. This results in charges that are pH dependent. These charges can also attract cations and are part of a soils CEC.

The general sorption characteristics of clay are partially a result of size. Clay crystals are small, yet have a large surface area. External surface areas of clay may range from a low of 30 m²/g to a high of 120 m²/g. Some clays also have what is called an internal surface that is greater than the external surface, as high as 600 m²/g. Depending on the type of clay, ions and molecules on the internal surfaces may or may not be released. Thus, it is conceivable that pollutants might become trapped on the internal surfaces, and not released under normal environmental or remediation conditions.

Chemical makeup is also important in determining the general absorption characteristics of clay. Clays are made up of aluminum and silicon bonded to oxygen. Each aluminum is bonded to six oxygen atoms, and each silicon is bonded to four oxygen atoms. Each form sheets. Aluminum attached to six oxygen atoms forms an octahedral (alumina) sheet. Silicon attached to four oxygens forms a tetrahedral (silicon) sheet. Tetrahedral (silicon) sheets and octahedral (alumina) sheets do not occur alone in soil. One or more silica tetrahedral sheets is associated with one or more aluminum octahedral sheets.

The type of clay is often referred to in terms of the numbers and types of sheets of which it is made. Kaolinite has a one to one structure. That is, it is made of one silicon tetrahedral sheet and one aluminum octahedral sheet as in figure one. Another common clay structure is two to one; two silicon tetrahedra with an aluminum octahedral sheet between them, as in figure two, page 40. With a one to one structure, each side or surface of the clay has different characteristics. In the two to one structure, each surface has the same characteristics.

The surfaces of clay crystals can be described in terms of being either a little positive or a little negative. In a one to one type clay, the one surface is a little positive—the upper, OH surface in figure one, and the other, the lower O surface in the diagram, is a little negative. In a two to one clay, both surfaces have only oxygens and are a little negative. Thus, a one to one clay can attract both negative and positive species. Two to one clays primarily attract positive species. In terms of water, the positive surface of the one to one clay attracts the oxygen atom in water, as in figure one, while the other surface attracts the hydrogen atoms.

Alfred Conklin is a professor in the agriculture department of Wilmington College, Wilmington, Ohio.
Figure one

Surface features also have an effect on how clay crystals interact with each other. It is a common chemical principle that differences attract and likes repel. In one to one clays, the surface of one clay crystal can attract the opposite surface on another crystal. Thus, it can form large stable clusters. Two to one clays tend to repel each other and form small clay clusters. This is fundamental to understanding clay behavior. However, clays are subject to isomorphic substitution and edge effects that also greatly affect their behavior.

Imagine that clay crystals are like dishes stacked one on top of the other. In one to one clays, the sheets stack closely with little water between them. With some two to one clays, there are water, ions and organic molecules between the sheets. The amount of water varies, so this type of clay is described as an expanding clay. When wetted, water, along with dissolved ions and organic molecules, move between the sheets and the clay expands. However, water, ions and organic molecules easily move out from between the sheets during drying. The result is shrinkage of the clay. This type of expanding clay is said to have a high shrink swell capacity. Montmorillonite is a common example of this type of clay.

In another common type of two to one clay, the layers are strongly held together and water, ions and organic molecules do not move easily in or out from between the layers. This is a non expanding clay. This type of clay is called either a fine-grained mica, or illite.

These two types of clay result from differences in isomorphic substitution. Isomorphic substitution occurs when, during the formation of the clay, an element replaces silicon or aluminum in the clay structure. For the substitution to lead to a stable clay, the substituting element must be approximately the same size as silicon or aluminum. The most common substitution is of aluminum for silicon in the tetrahedral sheets, and of magnesium for aluminum in the octahedral sheet. Substitution is common in two to one clays, but not in one to one clays. If the substitution is in the aluminum sheet, an expanding clay is formed. Substitution in the silicon sheet results in a non expanding clay.

Isomorphous substitution of Mg\(^{2+}\) for Al\(^{3+}\) is illustrated in figure three, page 41. The isomorphous substitution illustrated is common in two to one expanding clays.

Continues on page 40 →
Secrets of clay, from page 39

2:1 Clay Structure (Montmorillonite)

Figure two

One of the negative charges that the aluminum would normally satisfy is not satisfied. Thus, there is a net negative charge on the clay. This negative charge attracts cations—species with a positive charge. The most common cations are Ca$^{2+}$, Mg$^{2+}$, K$^+$ and H$^+$. Isomorphous substitution is one of the sources of a clays cation exchange capacity.

If there is isomorphous substitution of aluminum for silicon in the silicon tetrahedral sheet, two things happen. One of the bonds is not satisfied and the crystal is left with a negative charge. This is the source of CEC in fine grained mica type clays. Also, the surface of the clay crystal is deformed. The deformation leaves a pocket which is just the right size to accommodate a potassium cation, as in figure three. In turn, the potassium cation holds two crystals together such that this type of clay is non expanding. Other cations can also fit in this pocket, most notably, ammonium.

The edges of clay crystals also have unsatisfied negative charges that attract cations. These then are the other source of cation exchange capacity. These edges attract H$^+$ that neutralizes the charge. Thus, the amount of CEC resulting from edge effects is pH dependent.

As the pH increases, say from 4 to 8, the CEC increases because the protons on the edge dissociate. The magnitude of the edge effect depends on the clay crystal size. From kaolinite to illite to montmorillonite, clay particle size decreases, and the edge effect increases. Kaolinite and similar one to one clays also have surface OH groups which can also dissociate as pH increases.

The absorptive capacity of clay is determined by its crystal structure, isomorphous substitution and edge effects. It is possible for ions and organic molecules to be trapped between clay layers. The rate of release of such trapped material depends on clay structure and water content. The sorption due to general surface effects and isomorphous substitution cannot be changed. On the other hand, we can have some control...
2:1 Non-expanding Clay Structure (Illite)

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</table>

Figure three

of the edge effects by adjusting soil pH.

Theoretically, a decrease in soil pH would lower sorption, but in the field, this is generally impractical. First, soil has a very high buffering capacity, so that changing the pH is a slow process. Also, if soil is made very acidic, it decomposes, and the resulting material ceases to be soil, even if the pH is brought back to neutral.

When remediating clay soils, one must keep in mind not only the chemistry of the clay, but also its physical characteristics. Working clay when it is too dry or too wet tends to compact or puddle it. Another activity that compacts soil is to run traffic continuously over and over the same spot. When compacted or puddled, air and water move slowly through soil, which impedes a remediation effort.

A characteristic of soil which decreases compaction is its structure. Structure results from the bonding of sand silt and clay particles to form a secondary structure or soil ped. Ped formation is encouraged by calcium, organic matter in general, and microbial gum in particular. Microbial gum formation is increased by high microbial activity that is in turn, encouraged by the addition of organic matter. Keeping the pH around 7 and maintaining good organic matter content will typically benefit a remediation effort by encouraging ped formation which allows better air and water movement through soil.

Particles of soil organic matter are about the same size as clay and have high sorptive capacities and high cation exchange capacities. As much as 90 percent of its cation exchange capacity is due to pH dependent sites. Organic matter must always be considered along with clay content in any remediation effort.

Clay is a complex component of soil. Surface and cation exchange capacity characteristics are responsible for the sorption capacity of clay and cannot be changed. Edge effects can be changed, but only small changes are feasible in a remediation effort. The way soil is physically handled greatly influences how the soil clay content affects remediation. Keeping the characteristics of clay in mind when planning a remediation effort can greatly improve the efficiency of the project.
Interface probe measures up and down

Solinst Canada Ltd., Georgetown, Ontario, announces an oil/water interface probe that accurately measures the level and thickness of floating petroleum products, and sinking non-aqueous hydrocarbons, such as solvents (DNAPLS) as deep as 300 meters. CSA approved, and safe for use in hazardous locations, the model 121 meter is sturdy, simple to operate, easy to clean and decontaminate, says the company. Write in 816 for more information.

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CED Environmental Systems Inc., Ann Arbor, Mich., offers the Well Wizard™ Series 400 Controller with an on-board computer to deliver repeatable performance for MicroPurge™ sampling. Control settings and data for 500 wells can be stored in the unit. Its drive air regulator allows direct air pressure settings with a single turn of the knob, says the company. Write in 817 for more information.

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Sioux Corp., Beresford, S.D., line of steam cleaners provide 160°C steam to sterilize pumps, augers, instruments and other environmental equipment. It can remove tar, clean exchangers and screens, kill microorganisms and remove grease and mud, says the company. Models deliver up to 1800 liters per hour using either oil, gas or all electric power. Write in 819 for more information.
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CEA Instruments, Inc., Emerson, N.J. introduces the model TG-1900KA portable formaldehyde detector that uses a patented gas membrane galvanic cell sensor. It covers a range of 0 to 2 ppm and has adjustable alarms. It is self-contained, uses no paper tapes, reagents or gases and is sensitive well below TLV levels. Write in 823 for more information
The Fifteenth International Conference on Incineration and Thermal treatment Technologies, sponsored by the University of California, Irvine, will be held May 6-10, 1996, at the Savannah Marriott Riverfront Hotel in Savannah, Georgia, U.S.A.

For additional information please contact Lori Barnow or Jill Shook at TEL: (714) 824-7066 or FAX: (714) 824-8539. Interested contributors are invited to submit an abstract for review by Friday, October 11, 1995.

Any organizations interested in reserving exhibit space should also contact Ms. Barnow or Ms. Shook at the number listed above.
Don’t give up on pump and treat
Enhance it with bioremediation
By Samuel Marquis Jr.

Enhanced subsurface biological remediation has been proposed for an increasing number of sites where groundwater is contaminated with organic chemicals. In situ bioremediation uses water injection wells to supply dissolved oxygen and nutrients to the contaminated portions of the aquifer to stimulate the biodegradation of the contaminants by subsurface microflora. Proponents of pump and treat argue that although in situ bioremediation shows great promise, the technology has not proven superior to pump and treat in removing contamination from the saturated zone. Furthermore, it does not currently have a high level of regulatory acceptance, is subject to essentially the same hydrogeologic and geochemical limitations as pump and treat, it requires costly and time-consuming lab treatability studies and pilot studies prior to implementation, it does not provide for adequate plume containment and requires a team of specialized experts that would not necessarily be required for a pump and treat project.

The failure of pump and treat to meet cleanup goals is attributed to inherent subsurface heterogeneities, inherent factors associated with the dissolution, desorption, desorption and diffusion of contaminants, improper system design and unrealistic cleanup levels.

Proponents of in situ bioremediation have emphasized that bioremediation remediates both the contamination sorbed onto saturated soil and dissolved in groundwater, rather than simply transferring dissolved chemicals.

<table>
<thead>
<tr>
<th>REMEDIATION SCENARIO, DESCRIPTION</th>
<th>PLUME AREAL EXTENT (FT²)</th>
<th>PLUME CONTROL RANKING</th>
<th>MAXIMUM NAPHTHALENE CONCENTRATION (PPM)</th>
<th>CONTAMINANT REDUCTION RANKING</th>
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</tr>
<tr>
<td>13. Interior Injection/Exterior Injection (50 ppm DO)</td>
<td>7,500</td>
<td>V.Good(5)</td>
<td>5</td>
<td>Good(4)</td>
<td>High(0)</td>
<td>Good(9)</td>
</tr>
<tr>
<td>14. Areal Injection (8 ppm DO)/ Downgradient Extraction</td>
<td>31,500</td>
<td>V.Poor(1)'</td>
<td>10</td>
<td>Fair(3)</td>
<td>High(0.5)</td>
<td>V.Poor(4.5)</td>
</tr>
<tr>
<td>15. Areal Injection (50 ppm DO)/ Downgradient Extraction</td>
<td>2,000</td>
<td>Good(4)'</td>
<td>1</td>
<td>V.Good(5)</td>
<td>High(0)</td>
<td>Good(9)</td>
</tr>
<tr>
<td>16. Areal Injection/Exterior Injection (8 ppm DO)</td>
<td>23,500</td>
<td>Fair(3)</td>
<td>20</td>
<td>V.Poor(1)</td>
<td>High(0.5)</td>
<td>V.Poor(4.5)</td>
</tr>
<tr>
<td>17. Areal Injection/Exterior Injection (50 ppm DO)</td>
<td>18,500</td>
<td>Good(4)</td>
<td>20</td>
<td>V.Poor(1)</td>
<td>High(0)</td>
<td>Poor(5)</td>
</tr>
<tr>
<td>18. Interior Injection (50 ppm DO) and Extraction</td>
<td>28,000</td>
<td>Poor(2)'</td>
<td>5</td>
<td>Good(4)</td>
<td>High(0.5)</td>
<td>Poor(6.5)</td>
</tr>
<tr>
<td>19. Interior Injection (50 ppm DO) and Extraction</td>
<td>10,000</td>
<td>Fair(3)'</td>
<td>5</td>
<td>Good(4)</td>
<td>High(0)</td>
<td>Fair(7)</td>
</tr>
</tbody>
</table>

1: Plume area measured with planimeter using 1 ppm contour. 2: Plume control ranking based on plume area. Very good(5): 0 to 9,999 ft², Good(4): 10,000 to 19,999 ft², Fair(3): 20,000 to 29,999 ft², Poor(2): 30,000 to 39,999 ft², Very Poor(1): > 39,999 ft², Extremely Poor(0): > 39,999 ft² and more than one plume per contour interval. One point subtracted if plume has separated into more than one plume per contour interval. 3: Maximum naphthalene concentration contour (ppm) that can be contoured by graphics package SURFER (Golden Software, Golden, Col.). 4: Contaminant reduction ranking based on maximum naphthalene concentration contour (ppm). Very Good(5): 0 to 4.99 ppm, Good(4): 5.00-9.99 ppm, Fair(3): 10 to 14.99 ppm, Poor(2): 15 to 19.99 ppm, Very Poor(1): 20 to 24.99 ppm, Extremely Poor(0): > 24.99 ppm. 5: Estimated relative cost ranking. In Sisru Bioremediation - 8 ppm DO(2): Very Low (< $200,000), In Sisru Bioremediation - 50 ppm DO. Low (1.5) ($200,000-$249,999), Pump and Treat(1): Medium ($250,000-$299,999), In Sisru Bioremediation (8 ppm DO) and Pump and Treat(0.5): High ($300,000-$349,999). In Sisru Bioremediation (50 ppm DO) and Pump and Treat(0): Very High (> $349,999). 6: Overall performance ranking based on point values awarded for plume control, contaminant reduction, and relative cost rankings. Very Good: 11-12 points, Good: 9-10.99 points. Fair: 7-8.99 points. Poor: 5-6.99 points. Very Poor: < 4.99 points. 7: Scenarios in which one point was subtracted from plume control ranking due to separation of plume into more than one plume per contour interval.
to another phase in the environment and leaving sorbed contaminants in place. It can achieve target cleanup levels faster than pump and treat, can remediate low-conductivity soils and contaminants that would not be amenable to pump and treat. And, they would argue that bioremediation is more cost effective than pump and treat.

A computer modeling study was undertaken by McLaren/Hart Environmental Engineering, Irvine, Calif., to evaluate the effectiveness of pump and treat, in situ bioremediation and pump and treat combined with in situ bioremediation to clean up a chemical plume. The study also examined how injection and extraction well locations and injected dissolved oxygen concentrations affect remediation, and sought to identify the factors that limit the applicability and influence the success of the three technologies.

Input parameters for the study were taken from a field site under investigation by McLaren/Hart located in Gainesville, Fla. The hydrogeologically simple site is a wood preserving facility which contains a homogenous, single layer aquifer contaminated with naphthalene and other polynuclear aromatic hydrocarbons (PAHs). A total of 19 remediation scenarios were simulated, each incorporating different injection well locations, extraction well locations or dissolved oxygen concentrations in the injected water. The cleanup objective was to reduce the maximum concentration of naphthalene in the plume by the greatest percentage for the least cost without increasing the volume of contaminated groundwater in the aquifer or allowing the plume to spread beyond its original boundaries. Each scenario was ranked in terms of plume control and contaminant reduction, based on the computer modeling results and estimated cost for one year of operation in order to compare the alternatives.

Pump and treat versus bioremediation

Groundwater pump and treat methods use one or more extraction wells to remove dissolved contaminants by developing a hydraulic capture zone to encompass the plume under steady-state flow conditions. For a single well, the set of all horizontal groundwater flow paths that intersect the well over an infinite period of time defines the steady-state capture zone of the well and, in theory, groundwater and dissolved contaminants within this capture zone should be drawn to the well under continuous pumping. The groundwater removed during pumping is treated at the surface and discharged, either to a point where it does not supply any recharge to the aquifer, or to a point in the aquifer where it does not influence the velocity field around the pumping wells or enhance natural biodegradation.

The two most common ways to treat groundwater are with granular activated carbon adsorption and air stripping in conjunction with a carbon adsorption, thermal oxidizer or catalytic oxidizer of gas treatment system. Although pump and treat has historically been the most widely applied method to remediate organic chemicals dissolved in groundwater, the technology works best to remediate more soluble, less-sorbing fuel hydrocarbons, such as gasoline. It is less successful to clean up relatively insoluble, strongly-sorbing chemicals such as halogenated aliphatic hydrocarbons, halogenated benzenes, phthalates, polychlorinated biphenyls, motor oil and tree- to five-ring polyaromatic hydrocarbons.

In situ bioremediation remediates both saturated soil and groundwater by

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enhancing the natural biodegradation of the chemicals that are both adsorbed onto subsurface sediments and dissolved in groundwater. Water injection wells to supply dissolved oxygen and nutrients to the indigenous microflora in the contaminated portions of the aquifer which stimulates the biodegradation of organic contaminants by the native microflora.

If extraction wells are used to accelerate the transport of dissolved oxygen and nutrients through the plume, and the extracted groundwater is treated at the surface, then the technology is not just bioremediation, but pump and treat and bioremediation combined. Similarly, in states where reinjection of treated groundwater is approved by regulatory agencies, the treated water can be used to accelerate cleanup by increasing the hydraulic gradient by providing greater hydraulic control and enhancing natural bioremediation due to the increased dissolved oxygen which is delivered to the aquifer. Because groundwater extraction involves both hydraulic and biological processes to achieve mass reductions, this technology is also not pure pump and treat, but pump and treated and in situ bioremediation combined.

Dissolved oxygen can be introduced into the aquifer by injecting water that has been circulated through an air sparger, or amended with pure oxygen or amended with hydrogen peroxide. These methods differ in the levels of dissolved oxygen that they can provide, and in the cost and ease of handling the oxygen. The problem with air sparging is that it can only provide dissolved oxygen concentrations of 8 to 12 ppm, depending on the temperature of the groundwater. Although dissolved oxygen levels of 40 to 50 ppm can be achieved with pure oxygen, this chemical is relatively expensive, and may bubble out of solution before the microorganisms can see it, and is an explosion hazard if not properly handled.

Significantly higher concentrations of dissolved oxygen can be delivered to aquifers using hydrogen peroxide, which decomposes to dissolved oxygen at an approximate ratio of two peroxide molecules to one oxygen molecule. It has proved to be an effective source of dissolved oxygen at concentrations less than 200 ppm. In column studies of gasoline-impacted soils, microbial growth and BTEX degradation are typically greater in columns amended with hydrogen peroxide than columns amended with air or pure oxygen at concentrations less than 200 ppm.

**Modeling approach**

Computer simulations in the study used [PLUMEx II], a well documented computer code developed by Rice University’s National Center for Groundwater Research, under contract with the EPA. The code is a two-dimensional, numerical, solute transport code that simulates the movement of dissolved hydrocarbons under the influence of oxygen-limited biodegradation. The code assumes that dissolved oxygen availability is the only rate limiting factor in biodegradation. At every time step, the hydrocarbon transport equation is solved twice to compute the changes in hydrocarbon and oxygen concentration over time due to advection, dispersion and source/sink terms for hydrocarbon and oxygen. The resulting hydrocarbon and oxygen plumes are combined using the principle of superposition to simulate the instantaneous reaction between hydrocarbon and oxygen. A mass balance is performed for hydrocarbon and oxygen before the superposition of the two plumes and is adjusted for hydrocarbons lost by biodegradation.

To ensure that direct comparisons could be made of the effectiveness of the three methods, the number of wells, injection or pumping rates and hydrologic input parameters were the same for each scenario. The number of wells was selected to fully encompass the plume. Injection and extraction rate of each well were 3.8 liters per minute to maintain consistency between injection and extraction rates. Injected dissolved oxygen concentrations were set at 8 ppm, the typical concentration in tap water or air sparged water, and at 50 ppm, the maximum concentration in liquid oxygen, and typical low dissolved oxygen concentration using hydrogen peroxide.

The comparison also assumes that:

- the contaminant is readily biodegradable,
- an active microbial population is present,
- the aquifer is sufficiently permeable for injected groundwater to penetrate fully into the formation,
- high concentrations of acids, bases, heavy metals and salts which may inhibit biodegradation, are not present,
- oxygen is the only rate limiting factor for biodegradation and can be simulated by the stoichiometric ratio of oxygen to hydrocarbon required for complete mineralization to carbon dioxide, water and biomass,

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• the dissolved oxygen concentration of injected water is increased in a stepwise fashion during the initial phase of treatment to acclimate subsurface microorganisms to increased oxygen levels.

The stoichiometric ratio of oxygen to hydrocarbon consumed by microorganisms (F) is chemical and site specific and can be determined by lab electrolytic respirometer studies, or estimated based on model calibration of pilot test results. Based on previously reported F values for similar sites, the value of F was set at 3, the default value in BIOPUME II, which means that 3 units of oxygen are required to mineralize one unit of naphthalene.

Well configurations

The 19 remediation scenarios modeled the biodegradation and transport of naphthalene over a one year cleanup using different combinations of oxygenated water injection wells and groundwater extraction wells. The wells were placed to provide a range of general wellfield configurations for cleanup—including upgradient from plume, downgradient from plume, interior placement in the most concentrated portion of the plume, areal distribution throughout the plume area and wells positioned outside the areal boundaries of the plume.

The scenarios were ranked in terms of plume control and cleanup effectiveness, based on modeling results and estimated cost for one year using a numerical point system. The criteria for the point system used to rank the scenarios is shown in figure two, right.

Plume control refers to the degree with which a scenario can keep the plume from increasing in areal extent and restrict the plume from separating into smaller plumes or hot spots. Points for plume control were awarded on the basis of the area of the plume, with more points awarded to scenarios in which the plume decreased in size during remediation. For example, a plume control ranking of ‘very good,’ indicates that the plume decreased from the original area of 2,160 square meters to less than 900 square meters after one year, and is awarded five points. A ranking of ‘very poor’ indicates that the plume actually increased in size, and receives only one point. One point is subtracted if the original plume separates into more than one discrete plume per contour interval.

A ‘very good’ contaminant reduction

Continues on page 50→
Don’t give up, from page 49

ranking means that the maximum naphthalene isopleth has decreased from the original maximum of 30 ppm to less than 4.99 ppm—five points awarded. A ‘very poor’ contaminant reduction ranking indicates that the maximum isopleth is between 20 and 24.99 ppm, one point awarded.

The estimated relative costs are general project planning design estimates that include costs of:

- design, permitting, treatment unit construction and materials, startup and testing,
- installation and quarterly monitoring of each well for one year,
- operation, maintenance and quarterly compliance reporting for one year.

In addition, total estimated costs include quarterly monitoring of 10 additional groundwater monitor wells assumed to have been installed during the site characterization phase.

Using a relative cost ranking, in situ bioremediation using 8 ppm dissolved oxygen is the least expensive remedial alternative. The most expensive method is in situ bioremediation using 50 ppm dissolved oxygen in combination with pump and treat.

Only one scenario received a ‘very good’ performance ranking. It was an interior injection at 50 ppm dissolved oxygen. This scenario was characterized by ‘very good’ plume control and contaminant reduction and lowest estimated cost for one year of remediation.

The next best performance ranking was areal injection at 50 ppm dissolved oxygen. The poorest performers were:

- downgradient extraction
- areal extraction
- upgradient injection at 8 ppm dissolved oxygen with downgradient extraction.
- areal injection at 8 ppm dissolved oxygen with downgradient extraction and,
- areal injection with exterior injection at 8 ppm dissolved oxygen.

Although the best approach for groundwater cleanup is highly site-specific and depends on the hydrogeologic, microbiological and time and budgetary constraints, the modeling results suggest that certain general remediation scenarios perform better than others. In general, the scenarios that included pump and treat were superior to the other scenarios in containing the migration of the plume. Interior injection and areal injection with 50 ppm dissolved oxygen achieved the greatest contaminant reductions per unit cost.

Bioremediation cases in which only 8 ppm dissolved oxygen was injected, although less expensive, were not successful in controlling the plume or achieving major reductions in naphthalene concentrations. Scenarios consisting of bioremediation with 50 ppm dissolved oxygen and pump and treat combined in general achieved greater reductions in chemical concentrations than biorestoration at 50 ppm dissolved oxygen or pump and treat alone, but at greater cost. Greater chemical mass reductions occurred when extraction or injection wells were positioned in either the most concentrated portion of the plume or throughout most of the areal extent of the plume.

Based on the results of this study, these four scenarios should be considered in the design phase of in situ biorestoration projects:

- interior injection,
- areal injection,
- interior extraction with exterior injection, and
- areal injection with downgradient extraction.

Although the number of wells, injection and extraction rates and oxygen concentrations will vary from site to site, it is expected that interior injection and areal injection with downgradient extraction should perform well under high natural flow velocities. Areal injection and interior extraction with exterior injection scenarios should be more successful at sites characterized by lower natural flow velocities.

Under a high natural flow, the size of the stagnation area between the flow away from the injection wells and the natural gradient would be minimized during interior injection and groundwater and contaminants would move rapidly towards downgradient extraction wells during areal injection with downgradient extraction. However, under a high flow velocity, the zone of influence of widely spaced injection wells without accompanying downgradient extraction would be limited for areal injection, and the effectiveness of downgradient or crossgradient injection wells would be minimized during the interior extraction with exterior injection scenario.

Because in situ bioremediation typically offers the advantage of greater cleanup efficiency of both dissolved and adsorbed phase chemicals and lower costs than pump and treat, it is surprising that the technology has not been more widely applied. In spite of the currently limited application of biorestoration technology, the results from the current investigation and previous field studies indicate that in situ bioremediation and in situ bioremediation with pump and treat should always be considered as remedial options for sand and gravel aquifers contaminated with biodegradable organic compounds, especially volatile aromatic and polyaromatic hydrocarbons.

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50 August September 1995 Soil & Groundwater Cleanup
Murphy Equipment Corp. Terra Tech 3200

- The Terra Tech 3200, manufactured by Murphy Equipment Corp., Oklahoma City, Okla., can be towed to any site by a pickup truck, set up and operated by a single worker, says the company. The unit is 7.6 meters long and just over 2 meters wide. Excavated soils are dumped over the 4 cubic meter capacity hopper and screened through a 100 mm bar grizzly. Material is pulverized by two rows of hardened swinging hammers. A 110 hp turbo diesel engine powers the unit to process up to 150 cubic meters of contaminated soil per hour. After being conveyed through the mill, the material is thrown out the front of the machine, piling over 150 cubic meters before the machine needs to be moved. Additives and amendments can be added to site specific proportions before and/or after reaching the mill. Liquid material is injected via a water line, and dry additives can be fed through the hopper before mixing. In two recent tests, soil contaminated up to 2,800 ppm hydrocarbon product was cleaned to non-detectable in a 30 second trip through the machine. This was done with a mixture of pentanonic cleaner, manufactured by Surface Technology Co., Vista, Calif., mixed at a 35 to 1 ratio with water. Pentanonic cleaner breaks the hydrocarbon chain on contact, reducing it to harmless carbon and hydrogen. The pentanonic solution degrades naturally in the environment.

Clean, pulverized soil with the uniform consistency of sugar exits the Terra Tech 3200 unit in a windrow up to 4.5 meters wide and 3.6 meters high at the apex, says the company. Treated soils have an extremely high particle exposure to encourage the continued work of microorganisms to degrade trace contaminants and are suitable for backfill and recycling.

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Hopper can be fed by conveyor or screen plant

Manganese jaw crushes material to 3mm

1.2m wide discharge conveyor has self cleaning head drum

Portec Model 1047 EnviroJaw

Portec Environmental Products, Yankton, S.D., says their new Model 1047J EnviroJaw portable crushing system has application for environmental volume reduction applications, as well as concrete and asphalt crushing and recycling, block-brick volume reduction, construction debris, aggregate crushing and sand and gravel applications.

With a fully portable structural design that requires no setup or teardown for transport, modular bolt-on components allow the unit to be crated for ocean shipping to export markets.

The unit's 250 by 1200 millimeter manganese jaw can be fed by conveyor or chute from a portable screen plant. Teamed with the company's model 271 screen plant, production rates can easily exceed 90 metric tons per hour. When fed from a conveyor as a secondary crusher in a closed circuit operation, typical plant production can increase 35 percent or more.

The jaw accepts material up to 200 mm, and crushes it down to 30 mm. The closed side setting is adjustable from 75 mm down to 20 mm.

The entire unit is just under 8 meters in length and has a 1 meter end delivery conveyor self cleaning head drum sideboards. The unit features a 110 hp diesel engine with full instrumentation. The on-plant hydraulic system is designed to handle the 1.2 meter wide discharge conveyor in addition to an off-plant radial stacker for stockpiling. Self-cleaning head drum, wing style tail pulley and sideboards ensure a smooth discharge of crushed material.

The chassis is equipped with full air brakes and screw jacks to assist in cribbing. The entire plant is road legal at 2.5 meters wide. It weighs 13,500 kilograms and moves easily from site to site, says the company.

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