

ET-DSP™

Electro-Thermal Dynamic Stripping Process

Technical Description

ET-DSP™ In-Situ Thermal Remediation



MCMILLAN-MCGEE CORP.

CREATORS
OF ET-DSP™

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1. ET-DSP™ Technology

1.1. Process Description

In a typical application of the **Electro Thermal Dynamic Stripping Process (ET-DSP™)** electrodes are strategically placed into the contaminated zone. The pattern of electrodes is designed so that conventional three-phase power can be used to heat the soil. The distance between electrodes and their location is determined from the heat transfer mechanisms associated with vapor extraction, electrical heating and fluid movement in the contaminated zone.

A 3-D numerical simulation is performed on every project to verify the design.

To determine the ideal pattern of electrode and extraction wells, a multi-phase, multi-component, 3-D thermal model is used to simulate the process. Numerical modeling is also used to design the power delivery system, the power requirements from the utility, and the project capital requirements.

Many sites have been remediated using this technology. At all locations, contaminant removal was achieved typically in less than four months of heating. This is a direct result of a substantial temperature increase in the contaminated soil and concurrent increase in the vapor pressure. The increase in vapor pressure of the contaminants makes it much easier for them to be extracted from the soil.

Although the data from site to site varies, the typical cost for three-phase electrical power is a minor component of the overall cleanup costs for the project. Greater cost reductions are further realized as a result of the significant decrease in time required to complete the remediation.

Conventional remediation technology like soil vapor extraction has been utilized for the remediation of subsurface soils in the vadose zone and technologies like pump-and-treat have been used for contaminated zones within the groundwater system. These processes are limited by retardation of the contaminant in-situ, especially in fine sediments and clays. Therefore, primary technologies must be operated for long periods of time and may not achieve cleanup standards in low-permeability soils or where the vapor pressure of the contaminant is low.

ET-DSP™
increases vapor
pressure of
VOCs and
SVOCs for
easier recovery

Electrical heating increases the temperature of the soil and groundwater by conducting current through the resistive connate water that fills the porosity of the soil. The increase in temperature raises the vapor pressure of volatile and semi-volatile contaminants, thus increasing their ability to volatilize and be recovered through conventional techniques like soil vapor extraction.

For example, Figure 1 shows the vapor pressure relationship for benzene (C₆H₆). The curve represents the phase boundary of benzene. Above the curve, benzene naturally exists in the liquid phase and in the gas phase for conditions below the curve. An increase in temperature from standard conditions of 15°C to 80°C changes the phase of benzene from liquid to gas at atmospheric pressure. Normal operating conditions of the **ET-DSP™** process are indicated on the plot. The average pressure in the soil is reduced to 1/3 of an atmosphere as a result of extraction wells. The average temperature in the soil is increased to 80°C by ET-DSP™. Under these conditions, the benzene exists in the gas phase. The average temperature only has to exceed 50°C for benzene to occur in the gas phase during soil vapor extraction operations. Once the contaminant is in the gas phase, it is readily removed from the soil through vapor extraction wells.

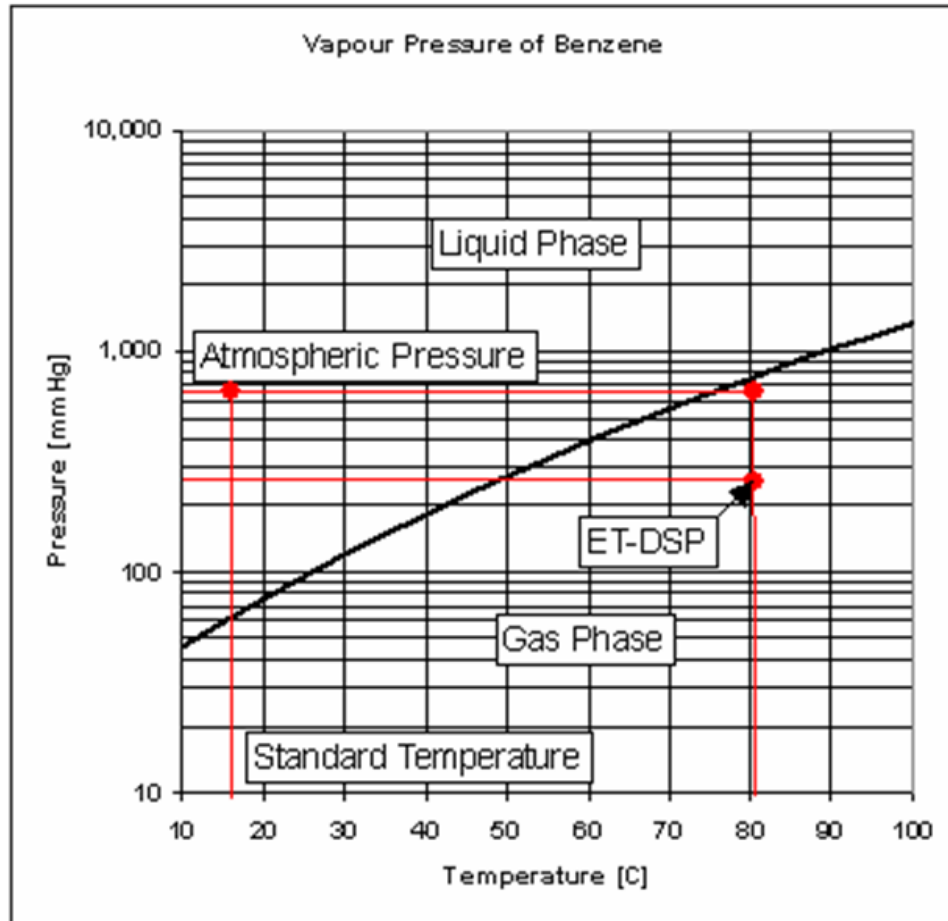


Figure 1 Vapor pressure of benzene

ET-DSP™
enhances
soil
permeability

ET-DSP™ heating also tends to dry the soil as steam vapors are produced. The creation of steam in the subsurface increases permeability and enhances the dynamic stripping effect of recovering contaminants that may not otherwise have been removed using only conventional extraction technologies. The temperature increase also expands the applicability of extraction to less volatile contaminants (SVOCs), and allows cost-effective remediation of lower permeability and more heterogeneous soils. This is demonstrated by the following figure of a clay sample recovered from an ET-DSP™ project at the end of 90 days of heating.



Figure 2 A clay sample recovered from an ET-DSP™ project

In addition to characterization of the site for contaminant concentration levels, electrical conductivity of the soil and its distribution should be measured. These involve measurements of the electrical properties of the soil as a function of temperature and water saturation. The data is important for the design of the Power Delivery System (PDS), estimation of the time required for heating the soil, determination of the power requirements, and numerical simulation of the heating process.

Extraction wells are placed as a means to aid in the transfer of heat

The electrodes are arranged so that the contaminated volume of soil is contained inside the periphery of the electrodes. The vapor extraction wells are located within the contaminated soil. The position of the extraction wells relative to the electrodes is determined so that heat transfer by convection within the porous soil is maximized, thus minimizing heat losses and increasing the uniformity of the temperature distribution.

1.1.1. Total Heat Transfer Solution

ET-DSP™ is a complete heat transfer solution that delivers all of the benefits associated with the mechanisms of conduction, convection, and electrical heating.

ET-DSP™ is a total heat transfer solution combining convection, conduction, and electrical heating

A conventional water handling and vapor recovery system are installed as part of the process. The water circulation system provides water to the electrode wells to prevent overheating. The electrode wells are designed with fluid injection capability. Therefore some of the injected water flows from the electrode wells towards the vapor extraction wells. The heat transported by fluid movement tends to heat the soil rapidly and more uniformly and is an integral stage of ET-DSP™. The produced fluids increase with temperature over time. These fluids are re-injected and the overall thermal efficiency is improved.

The current path is shared between the electrodes passing through the connate water in the porous soil. The temperature is controlled to minimize drying out of the soil until the latter stages of the heating process. As the soil changes in temperature, the resistivity of the connate water will typically decrease. Also, as the soil dries out, the resistivity will increase. A computer control system is installed to ensure that the maximum current is applied to the subsurface via the electrodes at all times.

The electrodes are connected to a three-phase power delivery system. The power delivery system is equipped with computer controls so that the power from the three phases can be alternated between the electrodes.

2. Safety

Designing and engineering safe electrical applications is the paramount concern at Mc². A detailed QA/QC program ensures that all of our equipment is comprised of UL, ULC, and CSA approved components. Further, all ET-DSP™ equipment is certified by ENTELA, a globally recognized equipment certification program approved under the US Department of Labor as a Nationally Recognized Testing Laboratory (NRTL) under OSHA.

Mc² has the electrical engineers and know-how to design a safe grounding system

The ET-DSP™ process itself is very safe utilizing a frequency wave that is very clean and having a negligible impact outside of the treatment volume. The process meets all NEC and IEEE519 specifications and regulations. This means that there is no interference in the surrounding area for communications, television, or radio transmissions.

Mc², however, does not stop there to ensure safe and proper operation of its ET-DSP™ systems. Each site has electrical characteristics that are unique to it. This could include the physical properties of the soil and groundwater to grounding issues associated with buried metal debris and utility corridors. Mc² has the experience and qualifications to engineer a safe and effective grounding system. Our team of electrical engineers, led by Dr. Bruce McGee, is comprised of the world's foremost authorities on electrical heating. Our guarantee to our customers is a safe and successful remediation project.

3. Controlling the Heating Process

McMillan-McGee Corp. utilizes a system of *Time-Distributed Control* and Inter-Phase Synchronization (TDC/IPS) to control the power to the electrodes. This process effectively controls the amount and timing of power sent to individual electrodes. For example, should it become apparent that certain electrodes are in electrically resistive zones resulting in cold spots, the power to the electrodes can be increased in these areas to ensure a uniform heating process. Using readily available three-phase power eliminates the need for expensive specialty transformers and higher capital costs.

TDC/IPS provides unparalleled uniformity of heating to the targeted soil. This method actually controls the electrical sine wave of three-phase power down to the millisecond such that each phase can be individually manipulated. Additionally, the power delivery system is replete with an assortment of voltage tap settings to further control the heating process. This system is fully programmable and can be accessed over the Internet for remote monitoring and control. This degree of customization and system flexibility ensures timely completion and achieving all remedial goals on any site.

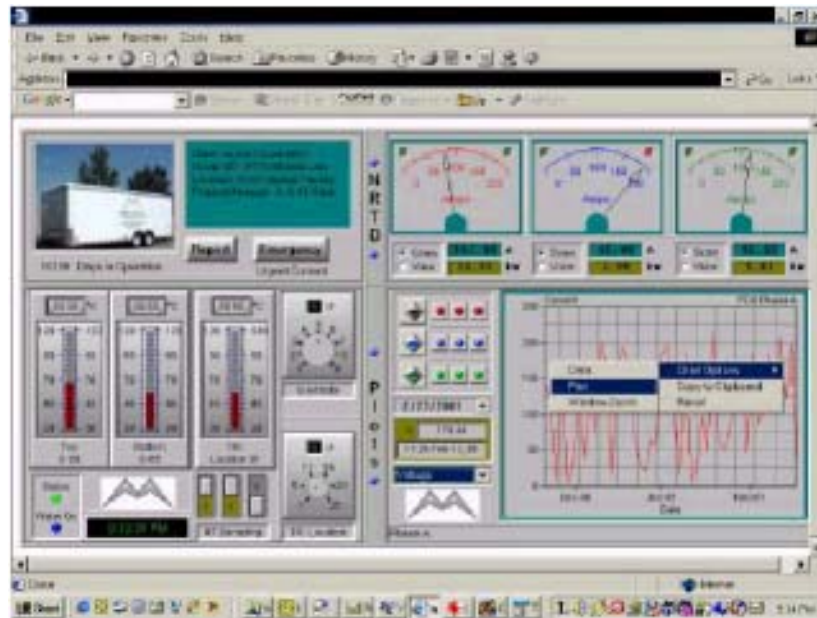


Figure 3 ET-DSP™ web-based control system

4. Numerical Modeling & Analysis

3-D
numerical
simulations
optimize the
ET-DSP™
process

Prior to the implementation of the ET-DSP™, McMillan-McGee Corp. acquires all of the available information for the site. This information should include, but not be limited to, the following: surface infrastructure, surrounding land uses, short term site usage during remediation, subsurface lithology, depth to groundwater, plume characterization, type of contaminant, distribution of the contaminant, and required time to attain target temperatures. The data is then examined and, through use of numerical modeling and analysis simulation software combined with a state-of the art bench-scale experimental station, the optimal thermal remediation strategy for the site is devised.

This modeling is important to determine optimum electrode configuration in terms of pattern type, shape, and separation; power supply requirements; power synchronization; optimal target temperature; and estimated time to attain the targeted temperature. The following figures depict the graphical output files that are typical of every numerical simulation report by Mc².

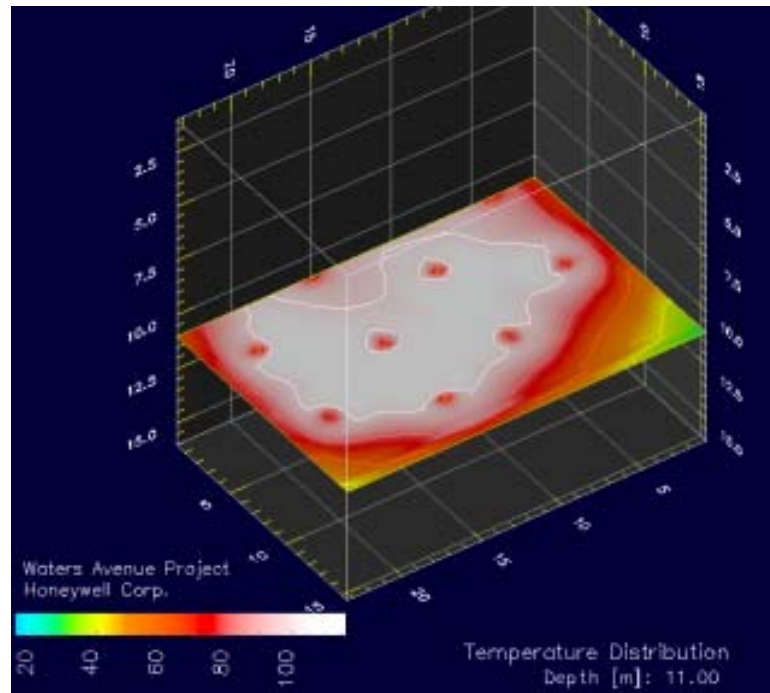


Figure 4 3-D numerical simulation of an ET-DSP™ temperature distribution.

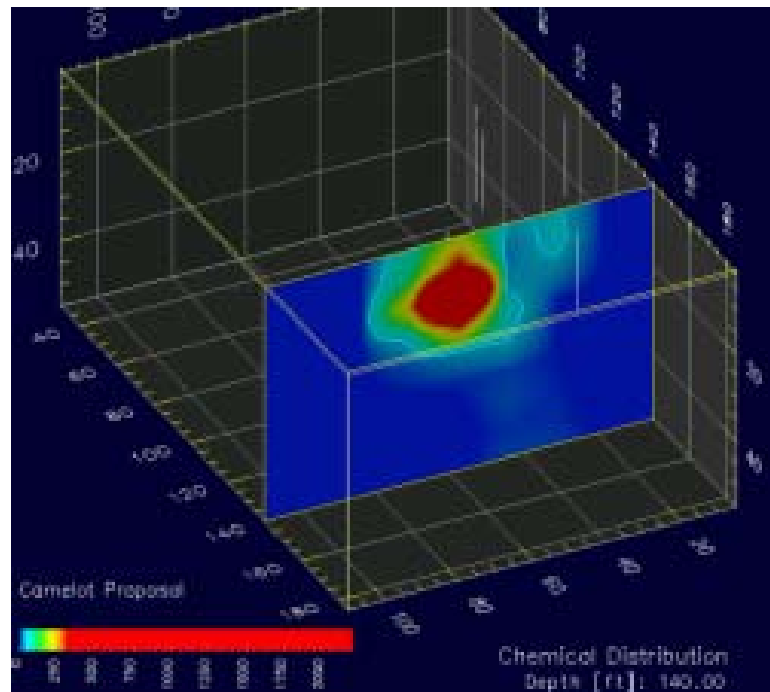


Figure 5 3-D numerical simulation of a contaminant distribution

5. Operations Management & Extraction

McMillan-McGee Corp. provides operation, optimization, maintenance, and project management expertise for all of their systems. The operations group includes individuals who possess an intimate knowledge of the US environmental market, expertise in geology and hydrogeology, and extensive contaminant extraction experience. Additionally, they ensure appropriate site selection, proper installation, and safe operation. The operations group will also provide in-depth training to companies who wish to conduct the day-to-day operations of ET-DSP™.

6. Where ET-DSP™ can be Used

ET-DSP™ is a very versatile technology that can be used under most conditions

ET-DSP™ is a tremendously versatile process and can be attempted at almost any site, regardless of soil type, where conventional in-situ remediation techniques are operated. ET-DSP™ is effective in desorbing contaminants from the soil particles both above and below the groundwater table, and can reduce dissolved-phase contamination. This technology is not limited by contaminant zone thickness or geometry, and can be applied at depths in excess of 100 feet. Our unique electrode design enables the electrode to be buried below grade; therefore, our system can be installed under buildings (vertical or horizontal electrodes), in high traffic sites, within streets, and in populated areas.

6.1. Subsurface Conditions

ET-DSP™ can be successfully utilized in vadose zone and saturated soils that are composed of highly organic soil, sand, gravel, silty sand, silt, clay and even bedrock.

In zones where the contamination is present at and beneath the groundwater, the soil resistivity is typically low and current is readily transferred from electrode to electrode. The soil and groundwater is heated, the vapor pressure of the contaminant increases, and, depending on the subsurface conditions and the solubility of the contaminant, extraction (vapor or groundwater) equipment performs the recovery.

In vadose zone heating, the most important feature for electrical resistive heating is moisture content. If the materials are excessively dry (<5%), the electrical resistive properties of the subsurface materials will be high. In essence, more electricity is required to heat a dry lithology than is required for moist ones.

McMillan-McGee Corp. has overcome these obstacles by designing each electrode with a water circulation system. By simply adjusting the amount of circulation fluid, dry subsurface materials can be moistened, thereby reducing the electrical resistivity of the subsurface materials. In subsurface materials like bedrock where the resistivity may be elevated, water-softening salts can be injected into the water circulation system. This results in lowering the

resistivity of the subsurface materials to achieve rapid heating.

6.2. Size and Extent of Plume

Electrodes
can be
configured to
fit any plume
shape

A competitive advantage that McMillan-McGee Corp. enjoys is that ET-DSP™ can efficiently heat contaminated plumes of any geometric shape. As mentioned, our process utilizes standard 3-phase electrical power where each phase is distributed to an individual electrode. This versatility allows us to closely match odd geometric plume configurations that require less heating of uncontaminated soil outside of plume boundaries. This results in less energy waste and passes cost savings on to the client.

As previously mentioned, electrode lengths vary up to ten feet in length. With a vertical heating profile of three feet above and below each electrode, the effective zone of ET-DSP™ heating is approximately 16 feet. In instances where a zone of contamination exceeds this thickness, multiple electrodes can be installed in a layered configuration. An example of an odd-shaped plume that the ET-DSP™ electrodes were configured around can be found in the following figure.

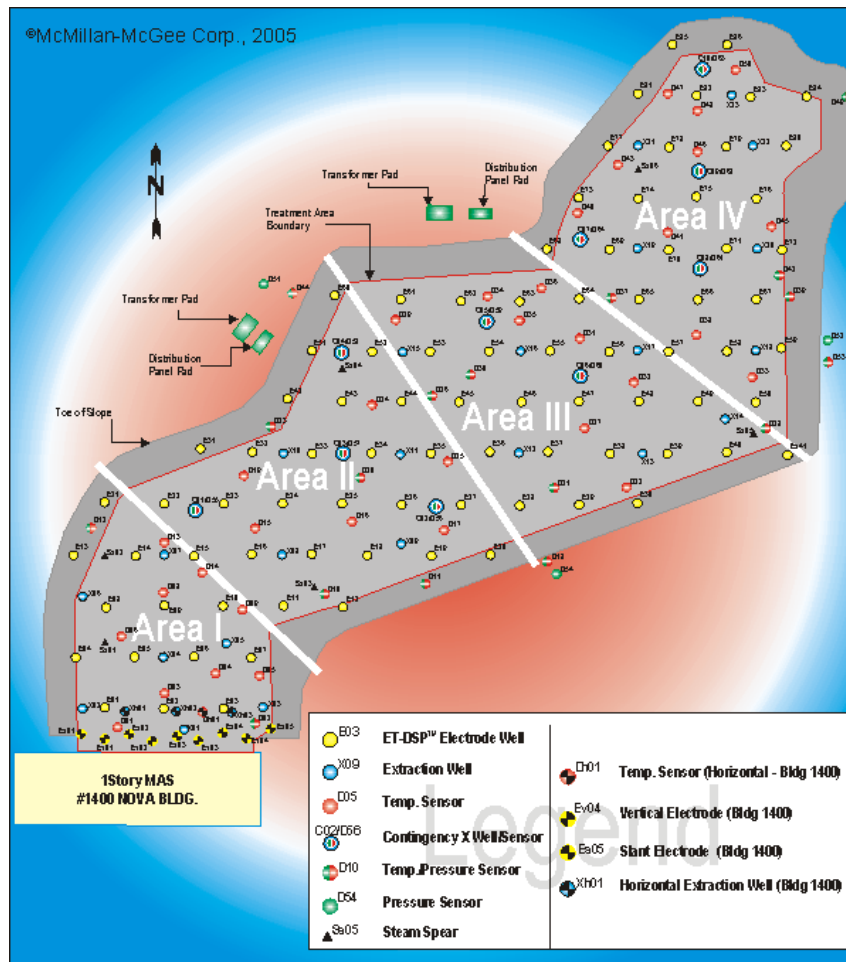


Figure 6 ET-DSP™ electrodes can be configured around any plume shape

6.3. ET-DSP™ in Urban Locations

ET-DSP™ can and has been used safely and effectively in populated areas. In fact, Mc² has installed and operated an ET-DSP™ system beneath an occupied apartment complex in a residential neighborhood and below a major US Highway as can be seen in Figure 7.



Figure 7 ET-DSP™ electrodes can be set almost anywhere

The system has a very small footprint and is very quiet

With the exception of the electrode cooling system and PDS, all of the equipment utilized for the heating is buried below grade. The electrodes are installed within the zone of contamination and the conductor cables and water circulation can be plumbed within a trench back to the PDS compound. The size of the PDS and water circulation system is approximately 8 feet by 12 feet square. This equipment can easily be installed within the same compound where the vapor extraction or multi-phase extraction equipment resides. The unique below grade design enables this system to be installed in active sites where traffic patterns must be restored immediately after trenching, increases the overall safety of the project (no surface access to the electrodes), no requirement for unsightly fences around property, and the ability for a site to remain active during remediation activities.

ET-DSP™ systems have been successfully deployed beneath buildings, highways, and in the presence of utilities

ET-DSP™ can be applied beneath buildings where conventional excavation often is cost prohibitive. Electrodes can either be installed vertically through the floor slab, vertically from an exterior wall, or horizontally beneath the structure. Vapor extraction piping must be installed between the zone of heating and the substructure for the building in order to collect vapors generated by the heating, to prevent the collection of vapor beneath the substructure of the

building, and to reduce the risk of vapor entering the onsite structure.

When properly installed, there is no risk for damage of subsurface utilities or personnel electrocution by touching manholes, fence posts, cathodic protection, or similar utilities. After activation, step potential tests are conducted on all surface aspects of the ET-DSP™ and all other structures and fences that may be in the area. The purpose of the touch and step potential testing is to ensure that the treatment area maintains a safe electrical environment for project personnel, generally considered to be less than 15 volts.

It should be noted that the main concern with subsurface utilities is heat. If any heat sensitive utilities are present within the treatment area temperature sensors will be installed and connected to a computer alarm system. Once the temperature sensor indicates that the soil in the sensitive area has reached a pre-determined temperature threshold (programmed into the computer controller), the power in that area of the grid is reduced or deactivated and a cooling system can be engaged. The area would not be reactivated until the temperature is sufficiently reduced. This technique can also be utilized in the vicinity of underground storage tanks, product distribution lines, or any other heat sensitive areas.

7. What Compounds can be remediated using ET-DSP™?

ET-DSP™ removes contaminants from the subsurface by increasing the overall temperature of the zone of contamination. The temperature increase results in an increase in vapor pressure of the compound, decreases viscosity of compounds with low vapor pressure, and can also result in an increase in the microbiological populations.

ET-DSP™ has been used to remediate VOCs, SVOCs, and even heavy compounds like creosote

Coupling all of these factors, ET-DSP™ can remediate volatile, semi-volatile, and long-chained hydrocarbon compounds. The following figure summarizes some of the compounds that can be remediated by ET-DSP™. The horizontal line on the graph indicates at which vapor pressure the primary mode of remediation is conducted by extraction or bioremediation. It should be noted that an elevation of subsurface temperature decreases product viscosities, thereby increasing recovery rates. Once the liquid product is removed, bioremediation is easily stimulated to complete the remediation. This technique is excellent in high molecular weight compounds like creosotes, light oil crude, and coal tar.

The following figure outlines some of the more common contaminants remediated using ET-DSP™.

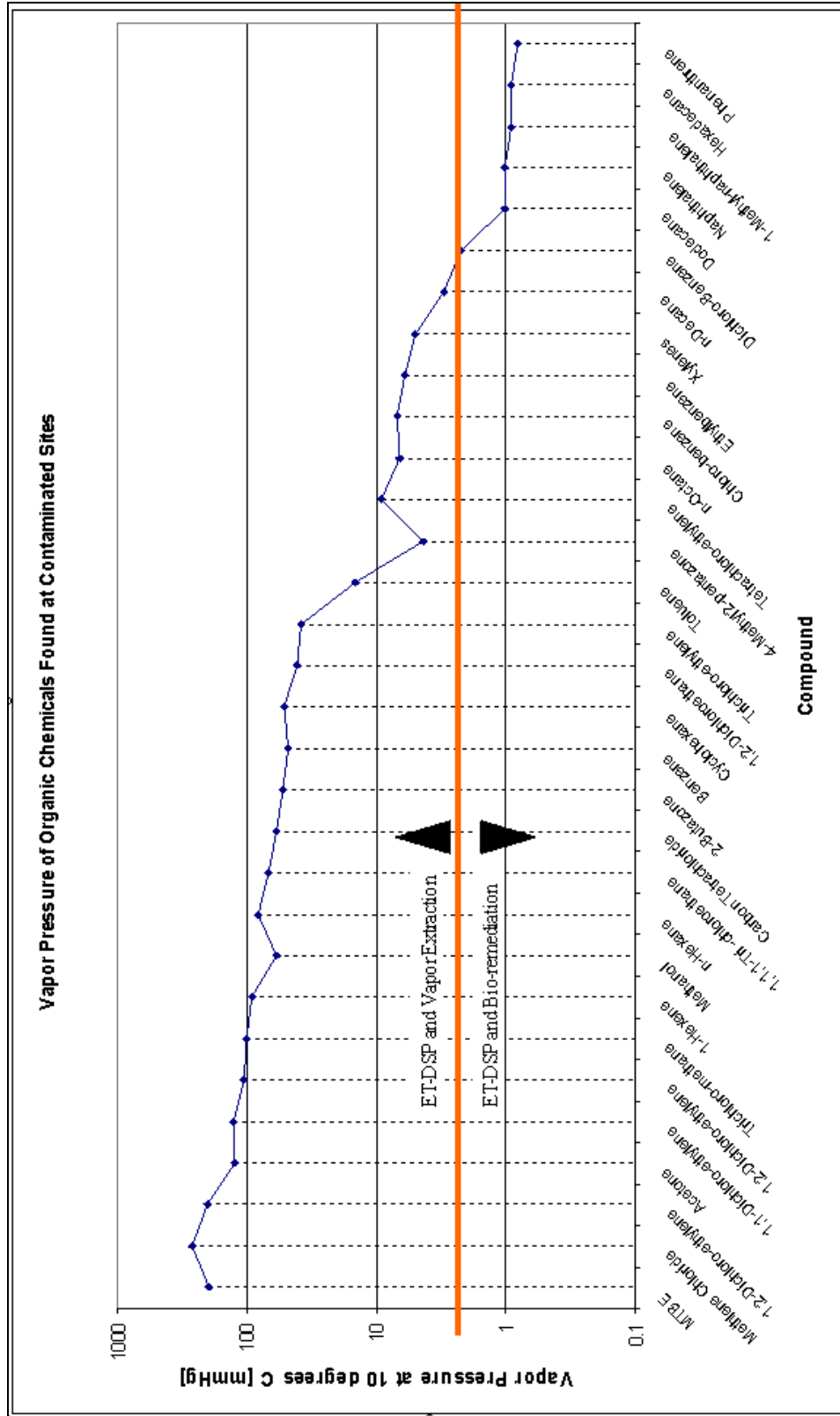


Figure 8 Common contaminants remediated using ET-DSP™

7.1. Accelerated Extraction of Volatile Contaminants

Increasing the vapor pressure of a contaminant partitions more of the compound into the vapor phase allowing vapor extraction or multi-phase extraction systems to recover the vapors more easily. Generally, the vapor pressure of a given compound increases with an increase in temperature (please see fi). However, at atmospheric pressure, not all compounds partition sufficiently to achieve clean-up levels within the operating temperatures of ET-DSP™ (75°C to 90°C). Based on this information, we have established that ET-DSP™ is effective in substantially accelerating (from years to months) the extraction process required to remediate volatile and semi-volatile organic compounds.

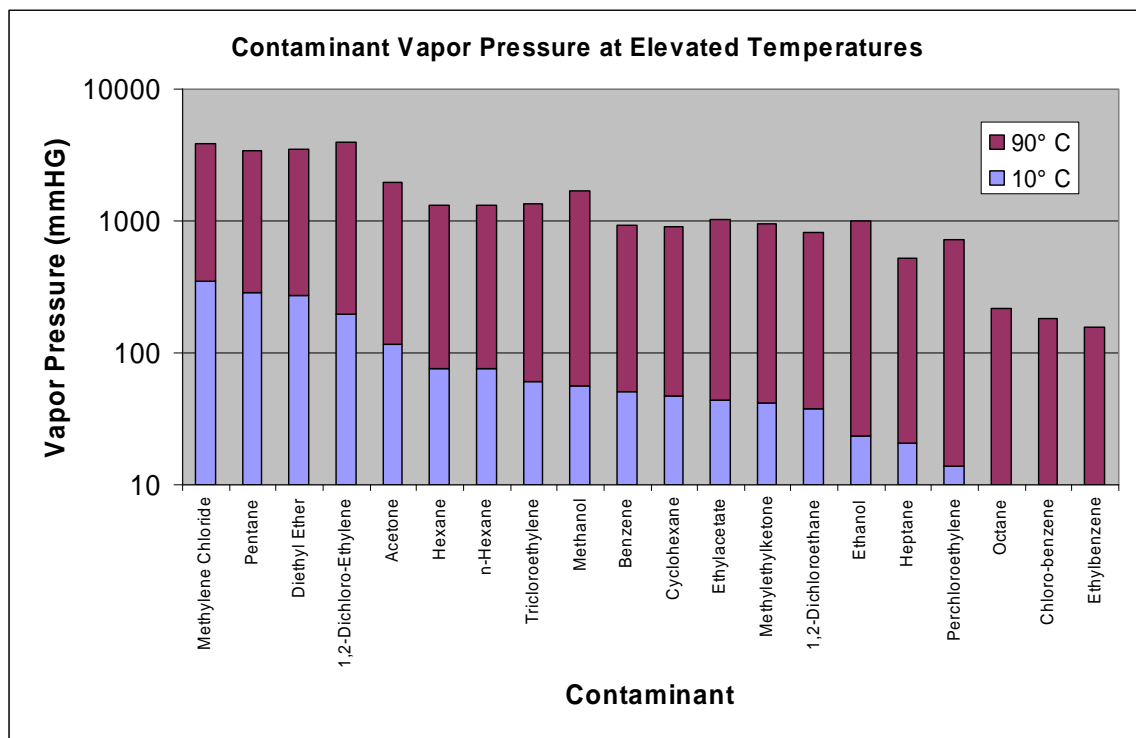


Figure 9 The effects of heat on vapor pressure

Based upon our experience we have determined that if a compound has a vapor pressure of 5 mm Hg or greater at 10°C, then ET-DSP™ will effectively reduce the contaminant concentrations through the use of extraction technologies. According to conservative estimates by the EPA, compounds with a vapor pressure of 10 mm Hg or greater at 10°C (the 10

–10 rule) are considered to compounds which are viable to be remediated by electrical heating.

7.2. Accelerated Bioremediation of Long-Chained Hydrocarbon Compounds

Microbes can be plated from almost all soil and groundwater samples collected from contaminant plumes. Larger populations of microorganisms consume more contaminants than do smaller populations. A well-known rule of thumb in the Environmental Industry is that microorganism populations double with every 10°C increase in temperature. Since subsurface temperature can be controlled using ET-DSP™, heating can be applied to levels sufficient to remove the more volatile organic compounds and then reduced and sustained at levels that are comfortable for microorganism consumption of the remaining long-chained hydrocarbon compounds.

8. ET-DSP™ System Components

All system components are manufactured to exacting UL, CSA, & ENTELA specifications

McMillan-McGee Corp. designs and manufactures all components of ET-DSP™. Each electrode, power delivery system, water circulation system, and power controller is designed, manufactured, and assembled at our state of the art facility to exacting UL, CSA, and ENTELA specifications. As a specialty manufacturer, Mc² controls all aspects of fabrication and component assembly. This production control eliminates project delays due to lack of equipment and allows Mc² to be responsive to our clients needs. As an original equipment manufacturer (OEM), Mc² also eliminates costly and unnecessary markups to the end user.

As indicated, the ET-DSP™ is a technique to enhance and substantially accelerate in-situ remediation by commercially available equipment. Typically, the electrical resistive heating equipment is installed in conjunction with standard vapor extraction, multi or dual phase extraction, air sparging, or groundwater pump and treat systems.

8.1. Electrical Equipment

The electrical resistive heating system consists of the following specialty components:

1. Power Delivery System (PDS),
2. Electrode Assembly, and
3. Water Circulation System.

8.1.1. Power Delivery System (PDS)

The Power Delivery System (PDS) is a computer controlled three-phase current transformer. These systems come in a range of KVA ratings and are fully modular for quick plug and play applications. Each PDS is equipped with an assortment of voltage tap settings that allow the unit to be highly flexible in soils/groundwater with varying resistivity. This means that ET-DSP™ can achieve rapid heating results in soil matrixes that range from tight clays to sands and even rock.



Figure 10 The ET-DSP™ power delivery system

8.1.2. Electrode Assembly

McMillan-McGee Corp.'s electrodes are custom made in diameters up to 12", are typically up to ten feet long, and are rated for up to 180°C (356°F) at more than 50kW.

The use of three-phase power synchronization means that the ET-DSP™ electrode patterns are not geometrically limited. This factor allows McMillan-McGee Corp. to target a contaminated plume with the most efficient number of electrodes while offering a high degree of customization.

The electrode assembly is designed to conduct current to a targeted volume of soil without overheating the adjacent soils. This is accomplished through an imbedded water circulation system (cooling system) inside each electrode.

The electrodes are fabricated from high temperature resistant materials and are connected to the PDS. To maintain good electrical contact with the soil, each electrode is installed in a borehole packed with granular graphite which is compressed to the surface of the electrode. Conductors are run from each electrode back to the PDS and are suitable for either above or below grade installation.

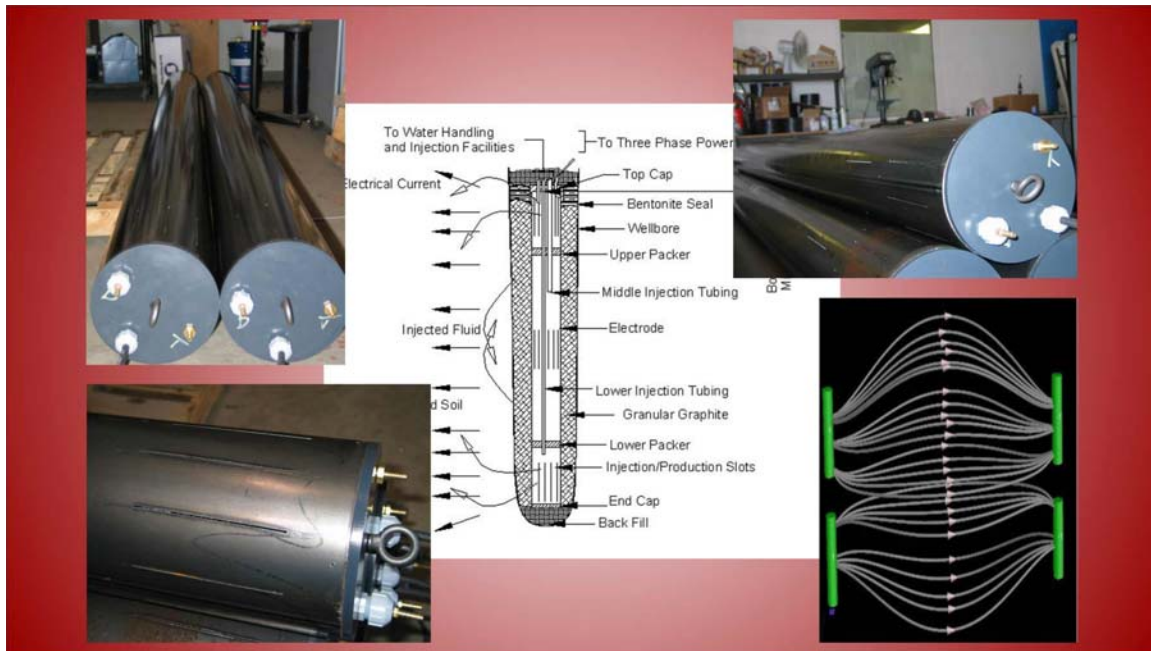


Figure 11 The ET-DSP™ electrode

8.1.3. Water Circulation System

The water circulation system is an integral component to the ET-DSP™ method. Without this system the electrode temperatures would rise and the surrounding soils would desiccate and become more resistive. The increase in soil resistivity increases the amperage draw on the PDS and can ultimately result in a main fuse, electrode or transformer failure. This can occur even at relatively low currents.

The Convective heat transfer of ET-DSP™ results in a more effective heat transfer solution

However, the most important function of the water circulation system is the heat transfer mechanism associated with convection. Physics dictates that the vast majority of the electrode's energy is concentrated at the ends. By purposely injecting at the ends, the water is heated to steam temperatures and is transported throughout the targeted volume. This both greatly enhances the heating process and allows ET-DSP™ to dynamically strip more SVOC's and other non-volatile contaminants such as creosote.

The water is distributed down the inside plumbing of the electrode, exiting the electrode through slots near the base and then washes over the outer surface of the metal. Some of the water is transported out into the subsurface soils to maintain the current pathway. The rest re-enters the

electrode through upper slots and is then re-circulated back to the water holding tank.

The amount of water that is directed into the formation is dependent on the permeability of the subsurface soils. In cases where soils of high permeability require heating, design changes to the electrodes are necessary in order to reduce the amount of leakage into the formation. Typical injection rates into the formation are usually on the order of 0.1 to 0.2 gpm per electrode. In most operations, this type of cooling operation is sufficient to maintain control on the maximum electrode temperature.



Figure 12 The ET-DSP™ water circulation system

9. Extraction & Treatment System

The extraction and treatment equipment utilized for the ET-DSP™ is commercially available off the shelf equipment.

Typical installations require the following:

1. Vapor/Groundwater Extraction System;
2. Extraction Wells and Header System; and
3. A Groundwater Treatment System.

9.1. Extraction System

Conventional SVE/MPE can be used to extract the produced vapors.

An extraction system must always be utilized when conducting electrical resistive heating. The proper design of the extraction system is absolutely necessary in order to optimize the system. Typically, high vacuum systems like liquid ring pumps, rotary positive blowers, and rotary vane blowers are utilized for the extraction systems. As the electrodes are cooled during the heating process, it is inevitable that the extraction system will remove water from the subsurface. For this reason, the extraction system must be capable of handling water (multi-phase extraction) during the extraction process.

In many cases, where heating is conducted at and below the groundwater table, larger quantities of groundwater are extracted and treated through the system. The extraction system is connected to the header (described below) and setup to extract both groundwater and hydrocarbon vapors from the subsurface within the electrode array. All recovered groundwater is transferred into the treatment system and then discharged. Contaminant vapors can be discharged into the ambient air or combusted, dependent on local regulatory requirements.

9.2. Extraction Wells and Header System

The design and location of the extraction wells is an integral part of ET-DSP™. The wells are placed within the electrode array in a spacing designed to maximize the recovery of the volatilizing hydrocarbons and designed to control the groundwater to minimize the potential for offsite migration

of the mobilized contaminant. Each well is connected to an extraction header pipe, which is connected to the extraction system. Depending on the contaminant of concern either steel or an approved thermoplastic can be used in the header system.

9.3. Groundwater Treatment System

The purpose of the groundwater treatment system is to remove dissolved contaminants and sediment from the groundwater. The treatment system typically consists of a sedimentation tank and an air stripper or granular activated carbon. Groundwater is transferred from the extraction system into the treatment system where the sediment and the dissolved-phase contaminants are removed. The clean effluent water is then discharged or removed by an approved method.

10. Experience

McMillan-McGee Corp. is the world leader in electrical heating of soil and groundwater. Our technology board is comprised of the world's leading experts in applied electromagnetics and electrical heating of porous media. Additionally, our team of electrical engineers is led by Dr. Bruce McGee, the world's foremost authority on electrical heating and thermal remediation.

ET-DSP™ technology has been used on dozens of sites across North America and in each case all remedial objectives were achieved on time and on budget. In fact, most ET-DSP™ sites have been cleaned to non-detect status and 'No Further Action' (NFA) closure is achieved.

Please call Brent Winder at 403.279.7948 for more information on completed projects and client references or visit our website at:

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