AN ALTERNATIVE TO VACUUM ENHANCED MULTI-PHASE EXTRACTION

BACKGROUND

After 25 years as a mechanical engineer designing production facilities for the energy industry, I had an opportunity about 10 years ago to specify and purchase a mechanical system for the remediation of a contaminated site owned by an upstream energy industry client. During the subsequent 10 years I have continued to work on remediation of contaminated sites, primarily specifying mechanical systems for the remediation of soil and groundwater. My expertise is therefore focused on the above ground portion of mechanical remediation systems, not on the in-ground portion.

In most cases the sites I work on are contaminated with light liquid hydrocarbons. The sites vary in size from a city lot to several acres in size. Light Non-Aqueous Phase Liquid (LNAPL) is present at some of these sites and absent at others.

When I began work in the environment industry, Vacuum Enhanced Multi-Phase Extraction (VEMPE) was a new technology, at least in Western Canada. At that time, most systems employed liquid ring pumps to generate vacuum. Although considerable work had been done with these systems in the US, local experience with this technology was limited. The technology seemed full of promise for the speedy and economical remediation of volatile hydrocarbons.. As is often the case with new technologies, some of the promise has been fulfilled as the technology evolved to meet local requirements. Some problems however have not been fully resolved.

Careful consideration of technical concerns and an examination of full life cycle cost is warranted in most cases and may provide an indication that an alternative technology is a better choice

SOME DEFINITIONS

In this presentation I will use the following terms and acronyms:

Vacuum Enhanced Multi-Phase Extraction (VEMPE) – Refers to the simultaneous extraction of groundwater (and associated liquids) and soil vapor by the application of vacuum to the subsurface. Most existing systems use a liquid ring pump to generate the required vacuum although more recently other vacuum devices have also come into use. The terms Multi-Phase Extraction (MPE) and Bio-Slurping are also used for this technology. This presentation refers to systems that use a vacuum source to extract both subsurface liquids and soil vapor as VEMPE.

Soil Vapor Extraction (SVE) – Refers to the extraction of soil vapor by the application of vacuum.

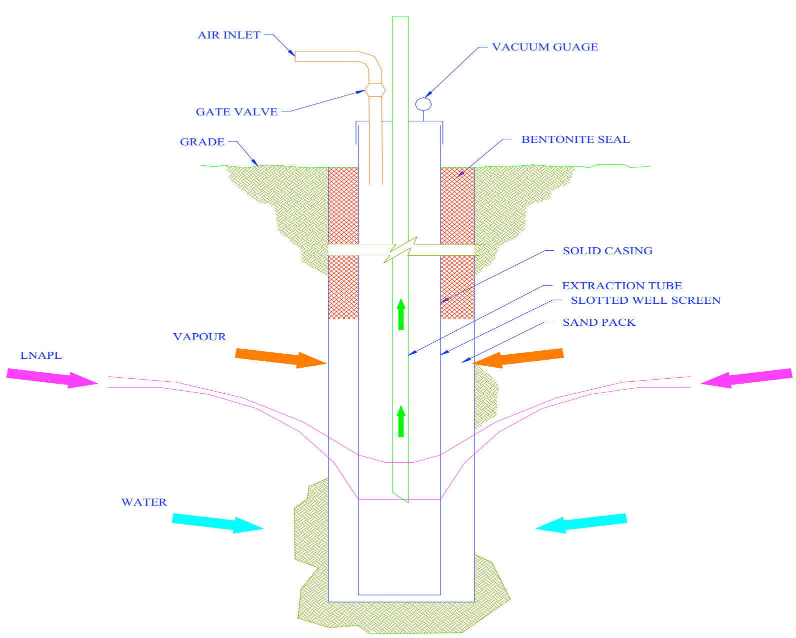
Liquids Pumping - Refers to the extraction of groundwater and associated liquid from the subsurface by means of pumping. Pumps used include positive displacement, diaphragm, peristaltic and centrifugal. This term does not include systems that extract subsurface liquids by the use of vacuum applied directly to the subsurface.

Dual-Phase Extraction (DPE) – Refers to the simultaneous use of SVE and Liquids Pumping to remove contaminants from the subsurface.

Liquid Ring Pump (LRP) – This is a centrifugal pump with a unique sealing mechanism that allows it to generate a high vacuum (typically 10 to 25 inches of mercury) while moving a multi-phase flow of liquid and vapor.

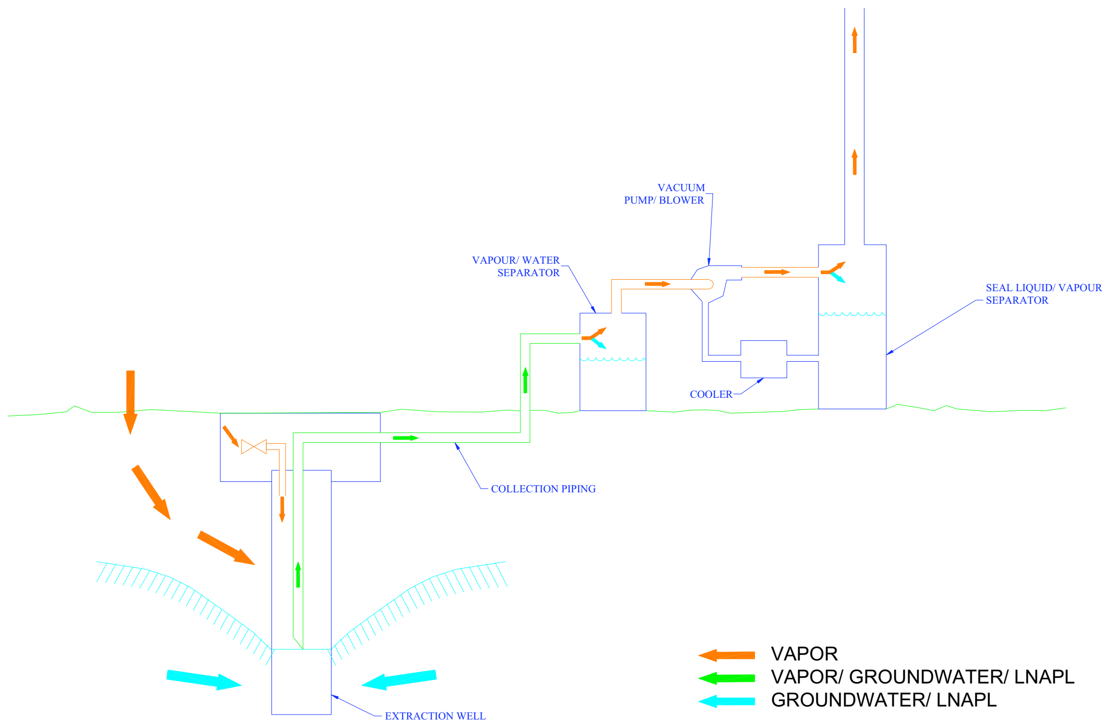
VEMPE SYSTEMS

VEMPE uses vacuum applied through a system of gathering pipes to one or more extraction wells to extract contaminants from the subsurface. The wells are typically screened in both the vadose (unsaturated) and phreatic (saturated) zones. A small diameter drop tube extends from the surface to the liquid/vapor interface as shown in Figure 1. Soil vapor enters the well bore through the portion of the screen above the water table. The differential pressure between the soil vapor and the vacuum source induces a flow of soil vapor toward the vacuum source. The vapor flow entrains liquid and carries it into the collection system in a multi-phase stream. If the soil vapor flow rate is insufficient to entrain adequate quantities of liquid, atmospheric air (bleed air) is admitted to the well to increase the vapor flow rate. The multi-phase mixture of soil vapor and liquid is conveyed to a separation and treatment facility via a system of pipes.



VEMPE EXTRACTION WELL
FIGURE 1

A vapor/liquid separator is usually provided upstream of the vacuum pump/blower to remove liquids from the multi-phase stream. Seal liquid circulates through the pump and is separated from the vapor stream in a seal fluid/vapor separator located downstream of the pump. This arrangement is shown in Figure 2.



VEMPE SYSTEM CONFIGURATION
FIGURE 2

Depending on the degree of contamination and regulatory requirements, extracted liquid and soil vapor may require treatment prior to disposal or release to the environment.

REMEDIATION USING VEMPE

Because of the high vacuum employed by VEMPE, volatile contaminants that have limited solubility in groundwater can be extracted relatively easily from the soil as soil vapor provided that the soil is adequately permeable. Contaminants that can be removed in this manner include the lighter hydrocarbons that are present in gasoline.

LNAPL present in the subsurface can be removed by a VEMPE system either through volatilization (if the product is reasonably volatile) or as a liquid as long as the LNAPL is accessible.

In addition to the above, any contaminants that are dissolved in the groundwater are removed along with the groundwater. As an added benefit, the vacuum employed by

VEMPE introduces an additional pneumatic gradient, which can enhance the overall rate of groundwater and LNAPL recovery.

Contaminants that are resistant to removal by VEMPE are primarily those that are inaccessible as a result of soil conditions.

Although ensuring that subsurface conditions are suitable is important to the success or failure of VEMPE in remediating sites, this is not the main focus of this presentation. For the purposes of this presentation, it will be assumed that the remediation technology selected is appropriate for the contaminants present and the subsurface conditions that will be encountered. In the real world this is of course not always the case.

In those cases where site characterization indicates that the contaminants of interest can be removed by the application of vacuum, VEMPE offers the following advantages:

- VEMPE is an aggressive treatment. High vacuum maximizes the extraction flow rates for subsurface liquids and soil vapor, thereby shortening remediation time. This reduces overall cost.
- Minimal equipment and piping are required resulting in a lower capital cost than other systems.
- Systems are available as off-the-shelf packages from a number of suppliers in Western Canada
- VEMPE is a well accepted technology for the remediation of contaminated sites

With the above advantages, it is understandable that VEMPE has become a popular choice particularly for remediation of sites contaminated with light hydrocarbons.

REASONS TO CONSIDER OTHER TECHNOLOGIES

During the time I have worked in the environment industry, I have been involved in the selection and installation of equipment for remediation of a number of contaminated sites. Also during that time I have been involved in the operation and maintenance of a number of VEMPE and other systems. It is this exposure to operating and maintaining VEMPE systems combined with the design of new systems that has motivated me to look at alternative technologies.

High Maintenance Cost

Although all equipment requires maintenance and will occasionally prove to be less than 100% reliable, equipment in VEMPE service seems to suffer more than its fair share of failures and also seems to require considerable routine maintenance if it is to operate satisfactorily.

I believe this to be due to a number of factors including:

- High operating temperatures – The high vacuum required to extract soil vapor and subsurface liquid combined with the need to discharge the vapor stream at a pressure above atmospheric results in a high compression ratio. This translates to considerable heat generation. Either the vacuum generation equipment has to operate at a high temperature or auxiliary cooling systems are required. Running equipment at high temperatures places extra load on lubricants and bearings. Auxiliary cooling systems have a potential for leakage and require monitors and/or controls to ensure that operating temperatures are not exceeded. These monitors and controls add to system complexity. In contrast, VES equipment running at relatively low levels of vacuum runs at lower temperatures. This makes minimal demands on lubricants and only requires rudimentary controls.

- The demands of VEMPE service – LRP's and other high vacuum generating equipment were originally designed in most cases to handle clean process streams with stable operating pressures and temperatures. In remediation service we often expect them to handle poorly filtered streams under varying pressure and temperature conditions. This can result in premature equipment failure.

With sufficient care, VEMPE equipment can be made to run reliably but unfortunately this goal is not always achieved.

High maintenance costs and lack of reliability are less important at sites located in or near population centers because of the ease of accessing the site. At more remote sites however, access may be difficult and costly which means that equipment maintenance costs are disproportionately higher and the system may have extended periods of shutdown. These increase the length of time required to remediate the site.

High Operating Cost

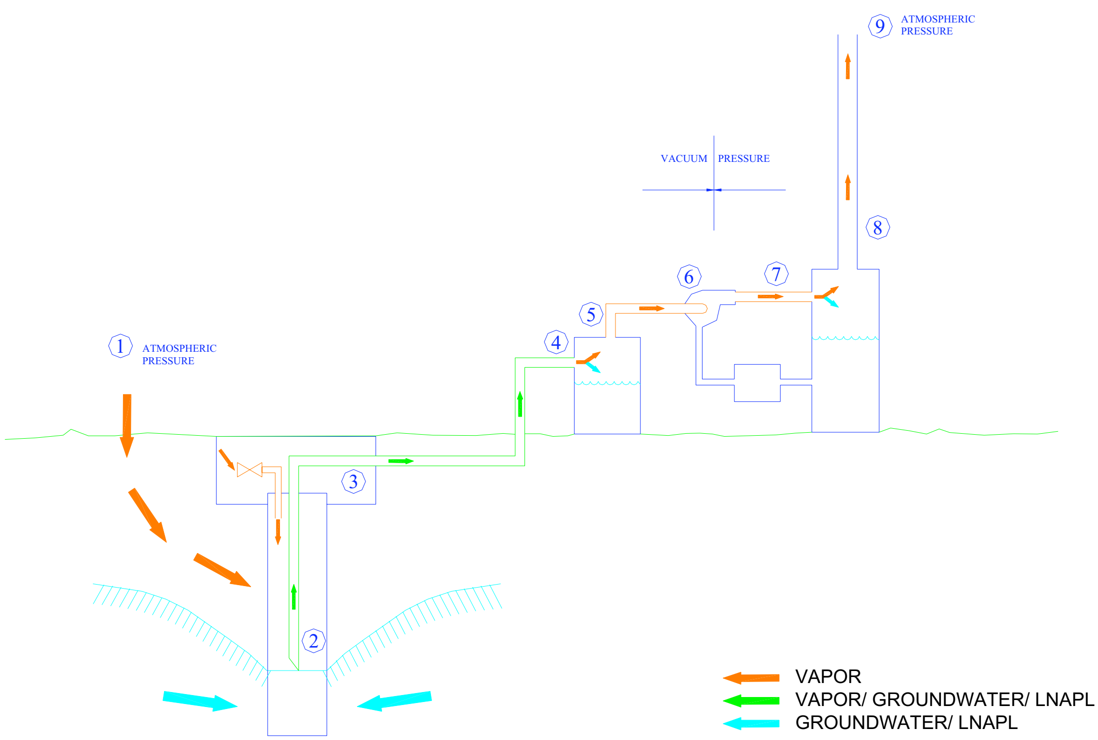
VEMPE systems also seem to suffer from high operating costs. I believe this is due to a number of factors including:

- High power consumption - Because of their unique method of operation, LRP's consume considerably more power than other types of compression or pumping equipment. This extra power is required to pump the seal liquid stream from the low pressure side of the pump to the high pressure side of the pump. The additional energy required for seal liquid pumping does not do any useful work but adds to the heat generated by compressing the vapor stream. This heat must be dissipated, necessitating the use of auxiliary cooling systems as described above.
- A single larger electrical motor – VEMPE systems use a single motor for all extraction work so the load is not broken down among a number of smaller motors, as is the case with the alternative remediation technology that will be discussed. Larger motors require higher voltage and draw more current than smaller ones. This may necessitate a separate power supply for the remediation system.
- Restarting after a shutdown – Quick re-starting of VEMPE systems after a shutdown can be difficult because of changes in the subsurface liquid/vapor interface level when vacuum application has stopped for a significant period of time. Operator attendance is usually required and a restart may take considerable time. At sites where shutdowns are frequent this can significantly increase operating costs.

The higher operating cost of a VEMPE system is not of major concern for smaller systems but as the vacuum pump/blower size increases, the operating costs become of greater importance. As a rule-of-thumb I begin to consider alternatives to VEMPE when the vacuum extraction motor reaches 40 horsepower.

Limited Collection Piping Length

Fluids flow in response to differences in pressure. Flow is from areas of high pressure to areas of low pressure. The complete pressure cycle of a VEMPE system from the atmosphere in the vicinity of the extraction well to the final venting of vapor to the atmosphere is illustrated in Figure 3. It may be seen that the fluid pressure declines from the extraction well (2) to the inlet to the vacuum pump/blower (6) so flow is from the extraction well to the vacuum pump/blower. The vacuum pump/blower boosts the fluid pressure to above atmospheric pressure so it can be discharged to the atmosphere (9).



VEMPE SYSTEM PRESSURE
FIGURE 3

Vacuum systems are subject to the limitation that the maximum pressure difference available to move fluids through the remediation system is the atmospheric pressure at the site. At sea level this is approximately 100 Kilopascals (kPa) or approximately 30 inches of mercury (in Hg).

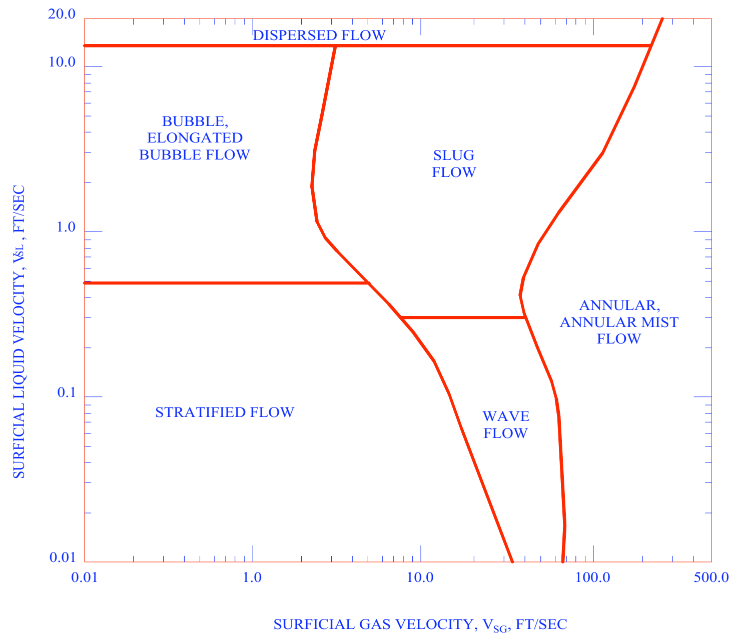
In VEMPE systems pressure difference has to provide the motive force to induce:

- Flow from the surface through the soil into the well bore;
- Flow up the extraction well into the gathering piping;
- Flow through the collection piping, and;
- Flow through the inlet separator.

With VEMPE systems it is generally desirable to minimize the pressure difference (usually referred to as pressure loss) required to move fluids through the extraction well, the gathering system and the inlet separator in order to maximize the pressure difference available to induce flow through the soil into the well bore.
The pressure loss in piping increases in direct proportion to the length of the pipe and decreases in inverse proportion to the fifth power of the pipe diameter. In other words, shorter, larger diameter pipes have less pressure loss than longer, smaller diameter ones.

Typically for single-phase (containing only vapor or only liquid) systems where the pipe length is determined by factors beyond the designer's control, the pipe diameter can be increased to reduce pressure losses. This however is not the case for VEMPE piping systems because they contain multi-phase fluids that impose additional constraints.

The behaviour of multi-phase flow is considerably more complex than single-phase flow because small changes in the amount of vapor and/or liquid flowing in the pipe can result in abrupt changes in flow pattern and pressure loss. As a result of research done at the University of Calgary and other sites, calculation methods have been developed that allow the prediction of the flow pattern and the pressure drop. Refer to Figure 4 for a sample flow pattern map (Mandhane, Gregory and Aziz: A Flow pattern Map for Gas-Liquid Flow in Horizontal Pipes, 1974).



MULTI-PHASE FLOW PATTERN MAP
FIGURE 4

Mmandhane, Gregory and Aziz: A Flow pattern Map for Gas-Liquid Flow in Horizontal Pipes, 1974).

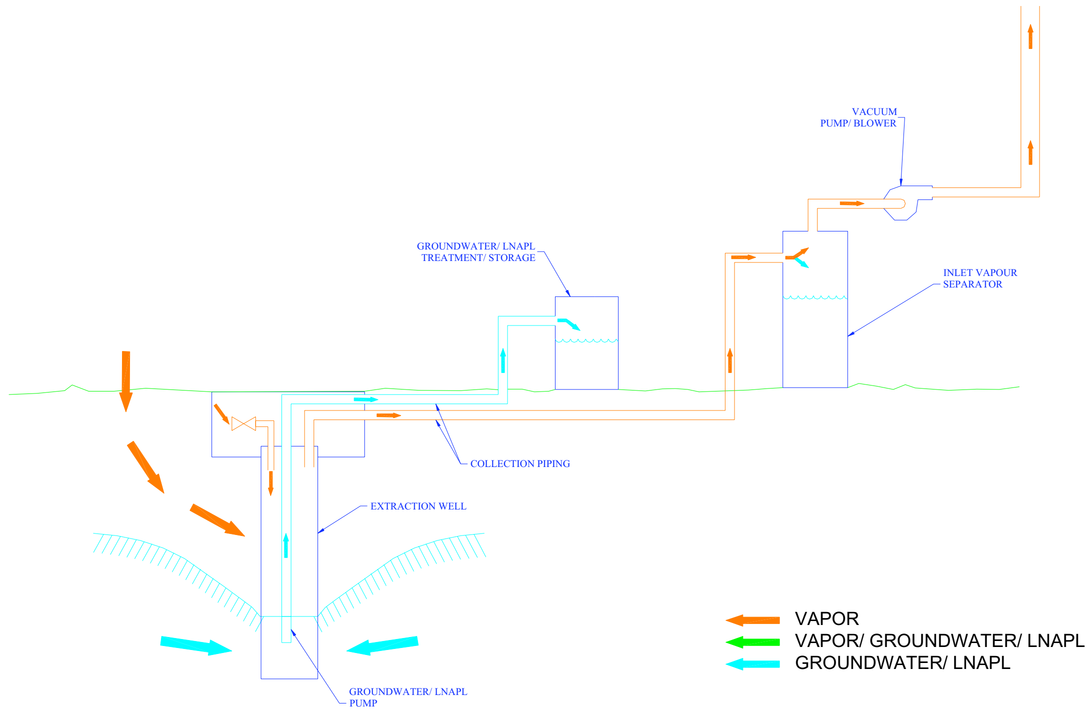
VEMPE system designers and operators have found it is best to operate in the annular and annular mist flow mode in order to avoid operational problems. As may be seen in Figure 4 this flow mode requires very high vapor velocities and as a result, the pressure losses are high. High vapor velocities and pressure losses also increase the power required to generate the vacuum.

In summary, it is the combination of the limited pressure drop available in vacuum systems and the large pressure drop required to ensure satisfactory operation of the gathering system that creates conditions that limits the ability of VEMPE systems to move fluids over longer distances. This is not a problem at smaller sites where gathering pipes are short but is a problem where fluids have to be extracted at a considerable distance from the vacuum pump/blower.

AN ALTERNATIVE TO VEMPE

At sites where it is necessary to extract both soil vapor and subsurface liquids but the high operating costs and limited collection range of VEMPE pose problems, an alternative exists which should be considered.

The alternative is Dual-Phase Extraction (DPE) utilizing separate systems to extract and collect soil vapor and subsurface liquids. The flow schematic for a typical DPE system is illustrated in Figure 5.



DUAL PHASE SYSTEM
FIGURE 5

Although the extraction well shown is designed for the extraction of both soil vapor and subsurface liquids, wells can be designed for the extraction of only one phase if desired. This is advantageous if the vacuum radius of influence is significantly different from the groundwater capture radius.

The use of DPE pre-dates the widespread use of VEMPE but VEMPE is now much more commonly used because of its simplicity and effectiveness. Unfortunately these qualities also result in VEMPE being used in cases where it is not the optimum choice.

The advantages of DPE include:

- DPE is more energy efficient – For systems of similar size the total power requirements of the electric motors in a DPE system can be 30% to 50% less than in a VEMPE system.
- The electric motor load in a DPE system is split among several motors which means that a lower voltage/lower amperage power supply can potentially be used.
- Soil vapor can be collected from a greater distance by using larger diameter piping which reduces pressure losses.
- Subsurface liquid can be collected from a greater distance by using pumps with a higher discharge pressures. The liquid collection piping design can also be

designed to prevent the build up of silt in systems where excessive silt production is anticipated. Generally, a higher velocity is used to prevent drop out of the silt in the collection piping.

- A DPE system can be designed so that the VES system operates independently of the Liquids Pumping system. By doing this, a malfunction in one system does not cause the other system to shut down. This increases the effectiveness of the overall remediation system.
- Restarting can be automated for some shutdown conditions such as a power failure because the system does not require rebalancing following a shutdown. This is particularly important for sites where access is difficult.
- The reduced pressure losses in the vapor collection piping may allow the system designer to substitute a rotary lobe or rotary claw blower for LRP. These devices are generally acknowledged to have lower maintenance costs than LRP's but may not be as suitable for generating the extremely high vacuums that LRP's are capable of.

The disadvantages of DPE include:

- The capital cost of DPE may be higher than VEMPE because of the additional equipment and piping required.
- DPE systems are more complex than VEMPE systems so care has to be taken to ensure that they operate reliably.

As mentioned previously, I find that the advantages of DPE become greater as the size of the system increases and that larger systems can benefit more from DPE than can smaller ones.

SUMMARY

VEMPE has become the technology of choice for sites where it is desirable to extract both soil vapor and subsurface liquids. It is easy to apply and equipment is readily available from suppliers.

VEMPE however, also has a number of drawbacks, some of which are not readily apparent. These include high maintenance costs, a lack of energy efficiency, a lack of flexibility, and an inability to convey collected fluids over longer distances.

In order to maintain the advantages of VEMPE while reducing its disadvantages, it is recommended that systems designers reconsider the older DPE technology. Sites where DPE can potentially offer the most advantage include those where:

- A large (40 HP or larger) VEMPE system is required to extract soil vapor and subsurface liquids.
- Collected fluids have to be transported over a considerable distance.
- It is desirable to substitute a rotary lobe or rotary claw blower for the LRP that most VEMPE systems use.
- Access for maintenance and operations personnel is difficult

- It is desirable to apply only vacuum or only liquid pumping to different areas at different times.

In cases where DPE is selected, the system designer should be cognizant of the additional complexity of DPE systems and should select equipment for maximum reliability and ensure that it is installed in a manner that will ensure reliable operation.