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The Internal Combustion Engine as a Low-Cost Soil Vapor Treatment Technology

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1.0 ABSTRACT

A low-cost and innovative soil vapor extraction (SVE) system using modified internal combustion engines (ICEs) to extract and destroy fuel hydrocarbons is successfully remediating a large JP-4 jet-fuel-contaminated site on Davis-Monthan Air Force Base (DMAFB), Arizona. Based on previous site investigations, soil contamination extended from near the ground surface to a depth of approximately 260 feet below ground surface (bgs). A maximum total fuel hydrocarbon concentration of 320,000 milligrams per kilogram (mg/kg) and a maximum soil gas hydrocarbon vapor concentration of 140,000 milligrams per liter (mg/L) were measured at the site. Prior to installing the full-scale SVE system using the ICE technology, bioventing and SVE with thermal oxidation were evaluated and determined not to be cost effective technologies for this site.

In 1994 Parsons Engineering Science, Inc. (Parsons ES), under contract with the Air Force Center for Environmental Excellence (AFCEE), conducted an SVE pilot test to collect cost and performance data on the ICE technology and to provide recommendations for the full-scale SVE system design. A full-scale SVE system using two 460-cubic-inch engines is now operating at a total volatile organic compound (VOC) removal rate of approximately 2,200 pounds per day, with a destruction efficiency exceeding 99.9 percent.

1.1 SITE HISTORY AND DESCRIPTION

The spill occurred at a jet fuel pumphouse consisting of nine 40,000-gallon and one 50,000-gallon underground storage tanks (USTs) containing JP-4 jet fuel, and an underground piping system that conveys the fuel to a fuel island. In 1985, a leak was detected in an underground fuel line, and an estimated 1.7 million cubic feet of soil were found to be contaminated with fuel. Jet-fuel contamination was detected in a soil column between depths of 8 and 260 feet. The groundwater is at a depth of approximately 300 feet.

From 1989 to 1993 remedial investigations and feasibility studies were completed under the U.S. Air Force Installation Restoration Program. The remedial alternative selected for the site included soil vapor extraction (SVE) followed by soil bioventing.

In 1993, an SVE pilot-scale test was performed by another contractor, and based on the results, a full-scale SVE system was designed. This design consisted of a series of 28 vapor extraction wells, a blower system, moisture separator, thermal oxidizer and catalytic oxidizer air treatment systems, propane tank, and associated piping and controls. The system was designed to operate at a maximum flow rate of 3,000 standard cubic feet per minute (scfm) with an operation period between 4 and 6 years in the SVE mode, then 2 years in a bioventing mode (at low rates of air injection). The construction/installation cost was estimated to be $1.72 million, with an operating cost of $23,400 per month for 4 to 6 years, for a total remediation cost of between $2.84 and $3.40 million (not including the 2-year period of bioventing treatment).

Because of the high cost for full-scale SVE treatment using thermal/catalytic oxidation, AFCEE contracted with Parsons ES to review alternative treatment technologies, including bioventing and the use of an ICE for vapor extraction and treatment. Results from a one-year bioventing pilot test indicated that biological degradation rates were too slow (10 to 50 mg/kg/yr) to remediate the highly contaminated soils (Parsons Engineering Science, Inc., 1994). Following the bioventing pilot test, SVE utilizing ICE technology was evaluated to determine the technical merit and potential cost savings of this technology.

1.2 DESCRIPTION OF ICE TECHNOLOGY

Vapor extraction and combustion is an innovative technology that uses an ICE with advanced emission controls to extract and burn nonchlorinated hydrocarbon vapors from the vadose zone. Vapors are extracted from the soil using the vacuum generated by the engine. The vapors are then burned as fuel by the engine. The exhaust gases pass through standard catalytic converters for complete oxidation before exiting to the atmosphere.

The ICE SVE system used at this site is equipped with an on-board computer system that provides the necessary monitoring for engine control. The 16-channel data reporting system monitors the engine's oil pressure/temperature, coolant temperature, exhaust temperature, exhaust percent oxygen, and engine speed and performance (extraction flow rate, inches of vacuum, supplemental fuel consumption, air/fuel ratio, and engine hours).

External electrical power is not required for this system because the electronic ignition is battery-powered. The ICE unit is equipped with a cellular phone modem for remote monitoring and to make necessary adjustments to engine speed to optimize engine performance and minimize supplemental fuel consumption. The remote monitoring capability allows for adjustments to be made while the unit is operating.

1.2.1 Pilot Test Using the V2C ICE

VR Systems, Inc., of Anaheim California developed the Model V2C ICE used for the initial pilot testing at DMAFB. The model V2C ICE system is capable of vacuum extraction flow rates ranging from 0 to 50 scfm, depending on soil conditions and the hydrocarbon concentrations of the extracted soil gas. Because this site has multiple extraction wells (EWs) screened at different intervals, the objective of initial pilot testing was to collect the following data:

1. Flow rates and pressure (vacuum) response and vapor concentrations at each EW screened interval;

2. Soil gas TVH concentrations before and after treatment at the ICE unit;

3. Changes in soil gas oxygen, carbon dioxide, and TVH concentrations both in the extracted soil gas and at multi-depth monitoring points; and

4. Overall cost to install and operate the system.

Based on the 90 day pilot test it was determined that the Model V2C could operate at 20-30 scfm and remove 200 to 300 pounds of volatile organics per day from the soil. Destruction efficiencies of 99.9% were achieved. The cost per pound of TVH removed decreased from $1.12/lb to $0.49/lb over the 90 day test period. Based on these positive results it was determined that the ICE was a cost-effective technology for removing and treating fuel vapors from this site. However, a larger unit would be required to accelerate and expand the clean up of the entire site.

1.3 SELECTION AND DESIGN OF A FULL-SCALE ICE/SVE SYSTEM

The data collected during the initial V2C pilot test provided the necessary information for the design of a full-scale ICE SVE system. The primary objectives of a full-scale system included a higher vapor extraction rate, lower cost per pound of TVH removed, lower maintenance/operating costs, remote monitoring/optimization capabilities, long-term reliability, and effective treatment of the entire site at the maximum design flow rate.

First, it was recognized that if an ICE system was purchased rather than rented, the cost per pound of TVH removed would be even lower than during the initial pilot test. Second, selection of the larger VR Systems Model V4 was made for the DMAFB site because of the elevated TVH concentrations (>40,000 ppmv) and the full-scale flow rate (120 to 150 scfm) that was required to remove vapors from the entire contaminated soil volume. The VR Systems Model V4 was also selected because of its remote monitoring/optimization capabilities and expected destruction efficiency of over 99 percent.

A redesigned full-scale SVE system utilizing an ICE vapor extraction/treatment system was installed in July and August 1995. The system included six vapor extraction wells completed at varying depths to focus vapor extraction in the most contaminated soil intervals, an ICE vapor extraction/treatment unit, a moisture separator, supplemental fuel propane tank, and associated piping and controls.

Well design and spacing were determined based on air permeability testing results, and flow rates were determined based on results of ICE pilot testing conducted from May to August 1995. The effective treatment radius for the full-scale ICE SVE system was determined based on radius of pressure response and changes in soil gas chemistry. Long term pressure response and soil gas monitoring indicated that the radius of influence from a single vent well exceeded 170 feet at a flow rate of approximately 20 scfm. During the bioventing pilot test, pressure response measured at a distance of 170 feet from the air injection wells exceeded 0.2 inches of water between 175 and 210 feet bgs (the depth zone with the most laterally extensive fuel contamination), and oxygen increases exceeded 10 percent. Pilot testing using an ICE confirmed that the vapor capture radius would exceed 170 feet at an air extraction rate of 20 scfm from each extraction well. ICE SVE pilot testing also indicated that initial flow rates exceeding 20 scfm from each extraction well could be maintained without the need for supplemental fuel (propane).

The vapor extraction wells used for the full-scale ICE/SVE system include the four existing wells installed for the initial SVE pilot testing and two additional wells installed in 1995. All extraction wells are constructed of 4-inch-diameter casing with stainless steel screens, and screened across soil intervals of relatively high fuel contamination and/or high permeability. The wells were screened at various discrete intervals between 60 and 233 feet bgs. All six vapor extraction wells were separately valved and then manifolded at a common point so that flow rates from individual wells could be easily adjusted by a site remediation technician.

The full-scale design of the ICE/SVE system included a maximum flow rate range of approximately 300 to 500 scfm using two 8-cylinder ICEs. A moisture separator was installed in the piping between the wells and the ICEs. A 250-gallon propane tank was installed to provide fuel for the ICEs during startup and for periods when the soil gas total volatile hydrocarbon (TVH) concentration temporarily falls below that required for proper ICE operation.

The ICE/SVE system used at this site meets the stringent Pima County, Arizona air emission standards which require that TVH emissions not exceed 2.4 pounds per day (lb/day). Based on laboratory analytical results for the ICE exhaust samples, emissions over the first 120 days have averaged approximately 0.54 lb/day.

1.4 PERFORMANCE OF THE FULL-SCALE SYSTEM

The attached table and figures provide the overall capital and operating costs as well as information on the cost per pound of TVH removed, and total pounds of TVH removed during the first 4 months of the V4 full-scale operation. Table 1 shows how the daily ICE/SVE operating costs were derived and compare these costs to the estimated cost of SVE using thermal oxidation for vapor treatment. During the first year of treatment, the ICE will average $0.065/pound of fuel removed compared to an estimated $0.77/pound for SVE with thermal oxidation. During years two to five, the increased use of supplemental fuel will increase the ICE's daily operating cost. However, throughout the life of the project, the ICE will maintain at least a seven-fold cost advantage over the SVE/thermal oxidation option.

Figure 1 shows the total mass (in pounds) of TVH removed over time during the first 4 months of V4 operation. A total of 255,318 pounds of fuel were removed and treated by the V4 ICE system during the first 120 days of full-scale operation.

Figure 2 shows the cost per pound of TVH removed over the initial 120-day period. The actual cost per pound of TVH removed and treated by the ICE ranged from 6 to 7 cents. This dramatic decrease in treatment cost over the initial pilot testing period using the V2C was due to the large increase in total mass removed when compared to a relatively small increase in daily operating costs. Eliminating the need for an electrical power hookup and having remote monitoring capability has also proven to be a significant cost savings.

During the initial 120 days of full-scale operation, 12 days of downtime occurred. All downtime was associated with a condensate/moisture collection problem. This problem was addressed by adding a larger water knock-out drum and by insulating the exposed piping. The overall uptime during the initial 120 days of operation was 90 percent. No mechanical ICE system failures occurred during this period.

1.5 SUMMARY

The VR Systems ICE SVE unit has provided very effective off-gas treatment for fuel hydrocarbons. To date, the Model V4 system has proven to be reliable, versatile, and cost-effective while removing over 255,000 pounds of fuel during the first 120 days of operations. The system has consistently

TABLE 1
CAPITAL AND OPERATING COST COMPARISON BETWEEN ICE AND THERMAL/CATALYTIC OXIDATION SVE SYSTEMS AT SITE 35, DAVIS-MONTHAN AFB

	VR Systems Model V4 ICE[a]	(Conventional) Thermal/Catalytic Oxidation SVE System[b]
Capital Cost		
Includes:		
Treatment Unit (includes engine rebuild)	$85,000	$354,000
Extraction Well Installation	$32,000	$666,000
Extraction Blowers	NA	$124,000
Design/Labor/Installation (includes contingency and profit)	$45,000	$580,000
Total Capital	$162,000	$1,724,000
Operating Cost (daily)		
Includes:		
• Capital [averaged over an estimated 5 year cleanup period (1,825 days)]	$89	$944
• Maintenance/Monitoring (includes monthly O&M and system sampling)	$57	$236
• Supplemental Fuel (daily) (includes propane and electricity)		
Year 1	$0	$544
Year 2	$34	$544
Year 3	$68	$544
Year 4 and 5	$102	$544
Total daily cost (Year 1)	$146	$1,724
Total pounds TVH Removed/day (Year 1)[c]	2,235	2,235
Total Cost/pound (Year 1)	$0.065	$0.77
Total Cost/pound (Year 5)[d]	$1.11	$7.73

a/ Cost based on actual purchases and labor by Parsons ES.
b/ Cost based on estimate supplied to Air Force by other contractor.
c/ Assumes that thermal/catalytic unit is limited to influent of 8,000 ppmv TVH for safe (non explosive) operation.
d/ Assumes 10-fold reduction in soil vapor concentrations by Year 5.

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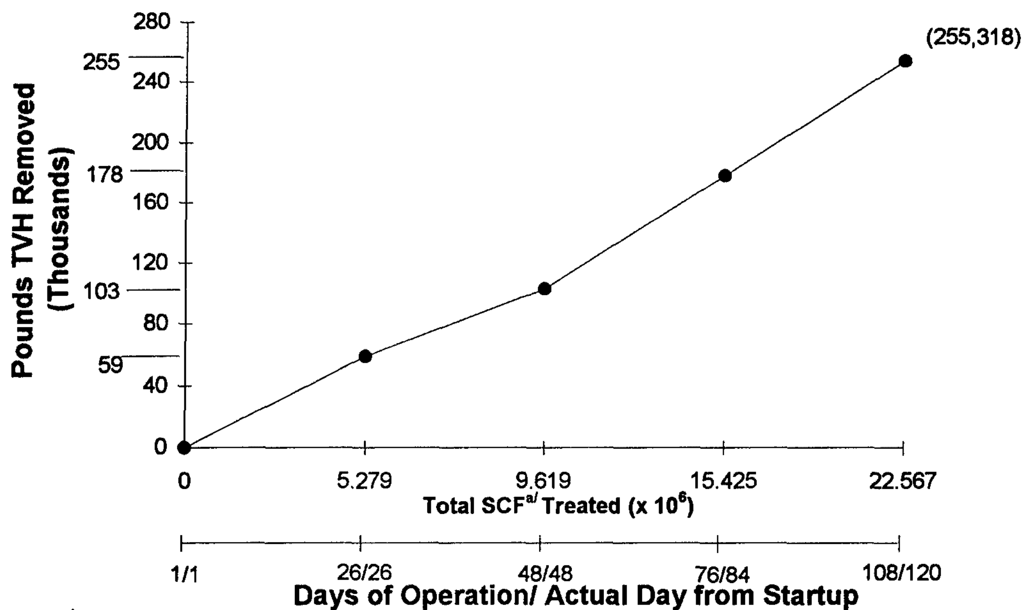
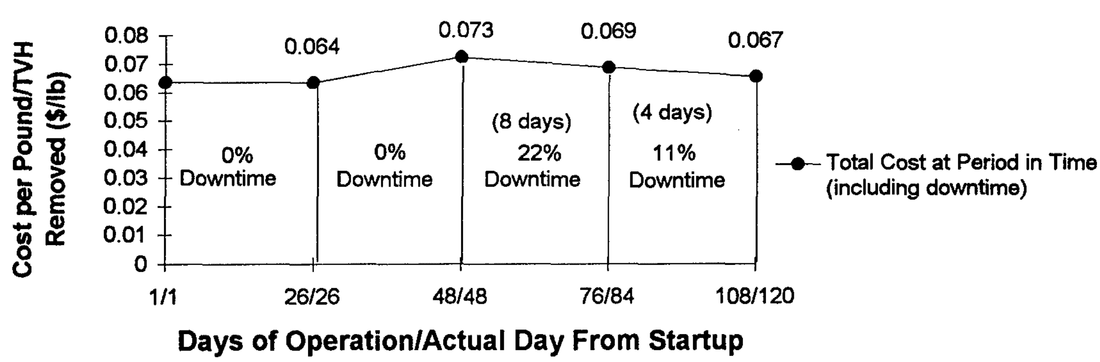
Figure 1
Total Pounds of TVH Removed
During Initial 120 Days of V4 Full-Scale Operation



[a/] SCF = Standard Cubic Feet

Figure 2
Actual Cost per Pound of TVH Removed
During Initial 120 Days of Full-Scale Operation Using the V4 ICE SVE System



achieved hydrocarbon destruction efficiencies of greater than 99.9 percent and remained in compliance with one of the nation's most stringent emissions standards.

1.6 FUTURE WORK

This technology has made significant advancements over recent years. VR Systems is currently fabricating a remotely monitored automated valving and flow rate monitoring system for this site so that the flow from individual extraction wells can be blended to provide optimum engine performance and minimum supplemental fuel use. The addition of remote valve controls should reduce technician site visits and labor hours associated with onsite system optimization at sites with a multiple extraction wells.

1.7 REFERENCES

Engineering-Science, Inc. 1994. Interim Pilot Test Results Report, Site ST-35 Fuel Pumphouse No. J3, Davis-Monthan Air Force Base. Prepared for U.S. Air Force Center for Environmental Excellence. June.