FIELD STUDY ABSTRACT
TEST RESULTS FOR LSTE-10

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Liquid Separation Technologies and Equipment, LLC (LSTE) has completed an economic analysis and field-based pilot test of it's new dual-phase remediation unit, the LSTE-10. This unit is designed to remove contaminants of concern ("COCs") such as BTEX, M*t*BE, *t*BA, PCE, and TCE from both groundwater and soil vapor in a cost-effective manner. The important results are as follows:

- The dual-phase LSTE-10 is a skid-mounted system that can be placed on site and operational with minimal time and effort (scalable).
- The LSTE-10 is best suited for sites where long-term operation is expected. The LSTE-10 becomes more cost competitive as concentrations and flow rates increase, and the longer the term of use.
- In financial models, the LSTE-10 was compared to Granulated Activated Carbon, Air Stripping, and Fluidized-Bed Reactors. The cost-per-gallon of treated effluent was evaluated as the modeling extended over a 10-year time period. In the longer term, the Granulated Activated Carbon was four times more expensive per gallon than the LSTE-10, Air Stripping was three times more expensive, and the Fluidized-Bed Reactor was six times more expensive.
- Based on the results of the field-based pilot test, the LSTE-10 is the most capable of the four remediation systems analyzed at effectively remediating the widest range of COC mixtures. All of the other systems have limitations as to one or more contaminants. For example, Granulated Activated Carbon and Air Stripping do not remove *t*BA and Fluidized-Bed Reactors need scrubbers to eliminate BTEX and cannot maintain high flow rates if concentrations increase.
- The LSTE-10 system generates the least amount of waste during operations, reducing overall costs.
- From a safety perspective, the maintenance requirements for the LSTE-10 are far below the other technologies, leading to reduced risk of personnel injury.
- The LSTE-10's more favorable system operation time and ability to respond rapidly to excursions in the influent concentrations minimize the potential for plume migration and the resultant increase in potential liability when the system is not operating.

Kleinfelder Field Study: The LSTE-10 Enhanced Treatment System for Removal of M*t*BE and *t*BA in Groundwater

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ABSTRACT

Results of a nine-month field study have validated previous pilot-scale evaluations of Liquid Separation Technologies & Equipment's Model LSTE-10 for treating methyl tertiary butyl ether (M*t*BE) and tertiary-butyl alcohol (*t*BA)-impacted groundwater. Based on in-shop pilot tests, the LSTE-10 has the dual-phase capability to effectively remediate soil and groundwater in cases expected to produce five gallons per minute ("gpm") groundwater and 200 SCFM of vapor.

The contaminant profile at the field site was similar to those frequently encountered at active retail services stations. Additional factors emphasized in site selection were the volume of influent to be treated and ease of parallel installation with the existing treatment equipment.

The field-test site had no appreciable levels of soil contamination. Consequently, the dual-phase capabilities of LSTE-10 were not factored into the economic analysis.

Removal efficiency, water flow rates, pressures and temperatures, as well as capital, maintenance and operational costs were evaluated. The study methodology directly compared the LSTE-10's performance with three other common treatment approaches: Granulated Activated Carbon (GAC), low-profile Air Stripping (AS) and ex-situ bioremediation via a Fluidized Bed Reactor (FBR).

All four systems require similar containment configurations. Of the four systems evaluated, the LSTE-10 requires the least amount of time from equipment delivery to full-time operation. With the LSTE-10, treatment can begin within one to two days of delivery. Another major advantage of LSTE-10 is the opportunity to reuse the system on multiple sites.

Based on data obtained during field trials, the LSTE-10 is best suited for projects expected to take more than three years for regulatory closure, involve multiple constituents of concern and/or require both soil and groundwater treatment.

1.0 STUDY METHODOLOGY

The study goal was to calculate a cost-per-treated gallon of influent assuming a fixed flow rate and a fixed process stream composition during one, two and five years of remediation system operation. The cost analysis takes into consideration the influent makeup, flow rate, capital outlay, typical construction costs and routine operations and maintenance (O&M) costs for the primary technology and all ancillary equipment. The cost-per-gallon for two, five and ten years of service is estimated by extrapolating the one-year cost out to two, five and ten years of operation. The field test site was chosen primarily to evaluate groundwater treatment in the presence of typical influent concentrations of benzene, toluene, ethylbenzene, xylenes (BTEX), M*t*BE and *t*BA.

1.1 Pilot Study

Prior to initiating field work, a pilot study was conducted. Each of the technologies evaluated responds differently to a particular suite of contaminants of concern (COC), operational criteria and environmental settings.

Four concentration regimes were modeled: low, medium, high, and free product as shown in Table 1. All concentrations are in parts per billion (ppb).

TABLE 1: PILOT STUDY CONCENTRATION REGIMES

Evaluation Sample	Concentration (ppb)		
	BTEX	M*t*BE	*t*BA
Low Concentration	1,250	1,000	1,000
Medium Concentration	10,000	10,000	10,000
High Concentration	100,000	100,000	100,000
Free Product	2,300,000	2,300,000	2,300,000

For comparative modeling purposes, flow rates were 2 gpm, 5 gpm and 10 gpm, respectively. These flow rates are consistent with retail service station remediation cases. During the pilot test, the LSTE-10 influent flow rates varied between 5.1 and 9.8 gpm.

1.2 Field Study Pressure and Temperature

This field study was performed on an existing, operating service station undergoing remediation of gasoline-impacted groundwater. To maximize COC removal efficiency and evaluate the LSTE-10 system controls, nozzle pressure, influent water and tower temperatures were varied. During the 90-day field test, nozzle pressure varied between 39 and 100 psig; influent water temperature varied between 68 and 95° F; and tower temperatures varied between 68 and 100° F.

1.3 Field Sampling Protocol

Influent and effluent samples were collected at four locations: 1) from the manifold connecting the LSTE-10 to the groundwater extraction wells; 2) from the sample ports following the aeration tank; 3) from the sample port on the oxidizer stack; and 4) from the sample port following the separator tower. All sampling protocol was conducted in accordance with EPA 5030/8015M for volatile fuel hydrocarbons and EPA 8260-B for BTEX and oxygenates. Samples were collected by directly filling laboratory-supplied containers from the sample ports. Samples were then sealed, labeled, and placed in an ice-filled, insulated cooler pending pickup by TestAmerica, a state-certified laboratory, for analysis.

2.0 COST BREAKDOWN

Capital costs included system components (i.e. piping, blowers, pumps, tanks, etc.) typically supporting each remediation system and are outlined in Table 2. Operations and maintenance (O&M) costs were based on a single technician visit at a typical rate of $70.00/hr and typical visit duration of three hours. Costs for replacing particulate filters, microbe feed stock, cleaning nozzles, etc. are included in the O&M costs as applicable for a specific remediation technology. Also, each remedial strategy requires a different level of preventive and corrective maintenance. Additional labor costs were factored into each strategy based on professional judgment and practical experience with these types of systems. Table 3 outlines utility costs for each system.

TABLE 2: COMPARISON OF CAPITAL COSTS

LSTE-10 System		Cost (catox)	Cost (carbon)
	Main LSTE-10 system	$ 170,000	$ 145,000
	Polish Carbon (2- 1000 lb Carbon Vessels)	$ 2,981	$ 2,981
	Total	**$ 172,981**	**$ 147,981**
Granulated Activated Carbon (GAC) System			
	Carbon Vessels (4- 2000 lb Carbon Vessels)	$ 25,375	
	Surge Tankage (2- 200 gal poly tanks)	$ 850	
	Transfer Pump	$ 500	
	Total	**$ 26,725**	
Fluidized Bed Reactor (FBR) System			
	Main Bioreactor system	$ 83,000	
	Transfer Pumps (2 pumps)	$ 1,000	
	Sacrificial Carbon (2- 500 lb Carbon Vessel)	$ 1,190	
	Polish Carbon (2 - 1000 lb Carbon Vessels)	$ 2,981	
	Total	**$ 88,171**	
Air Stripper (AS) System			
	Low Profile Air Stripper (6- tray)	$ 53,000	
	Vapor Treatment (2- 500 lb Vapor Carbon Vessels)	$ 1,250	
	Polish Carbon (2 - 1000 lb Carbon Vessels)	$ 2,981	
	Surge Tankage (2- 200 gal poly tanks)	$ 850	
	Transfer Pumps (2 pumps)	$ 1,000	
	Total	**$ 59,081**	
	Vapor Treatment (300 SCFM Catox; high conc)	$ 48,000	
	Total	**$ 107,081**	

TABLE 3: COMPARISONS OF OPERATIONS & MAINTENANCE COSTS

Technology	Average Monthly Power Usage (KW-hr)	Power Cost ($/KW-hr)	Annual Cost ($)	Monthly Cost ($)
LSTE-10	15,308	0.073	$13,409.81	$1,117.48
Granular Activiated Carbon	243	0.073	$212.87	$17.74
Fluidized Bed Reactor	1,568	0.073	$1,373.57	$114.46
Air Stripper (Carbon)	5,687	0.073	$4,981.81	$415.15
Air Stripper (CatOx)	11,588	0.073	$10,151.09	$845.92

3.0 OPERATIONAL DATA

The LSTE-10 becomes increasingly cost-effective the longer the system remains on site. The LSTE-10 was placed upstream of an existing GAC system operating at a local service station to ensure compliance with the service station's Elsinore Valley Water District Publicly-Owned Treatment Works (POTW) discharge permit. Table 4 outlines the LSTE-10's performance results after approximately nine months of active, on-site remediation.

TABLE 4: LSTE-10 OPERATIONAL DATA

	Run Hours	% Uptime	Total Gallons Processed	Avg TPHg Removal %	Avg M*t*BE Removal %	Avg *t*BA Removal %
March	426	81.0%	68,238	92.3%	94.1%	98.1%
April	612	85.0%	86,146	97.2%	94.5%	100.0%
May	618	95.0%	29,430*	93.4%	93.0%	100.0%
July	357	82.0%	105,386	97.4%	98.7%	100.0%
August	357	81.0%	97,161	100.0%	100.0%	100.0%
September	345	85.0%	146,918	100.0%	99.1%	100.0%
October	357	80.0%	135,374	100.0%	97.2%	100.0%
November	538	81.0%	150,344	93.7%	98.9%	100.0%
December	540	82.0%	75,400	100.0%	97.5%	100.0%

One component of remediation which is difficult to evaluate solely on a cost basis, is the risks associated with using hazardous materials, generating hazardous materials and general safety during system operation. Table 5 describes various risk potentials.

TABLE 5: COMPARISON OF RISK POTENTIALS

	LSTE-10	GAC	FBR	AS
Hazardous Chemicals required for O&M (*i.e* cleaning, etc.)	None	None	M*t*BE for additional feed during colony build-up	Muriatic acid for cleaning trays
Waste material generated from O&M	Spent Carbon	Spent Carbon	Spent Carbon and Biomass	Waste Acid and Spent Carbon
Safety Concerns with operations	Potential injury during carbon change-out activities.	Potential injury during carbon change-out activities.	Potential injury during carbon change-out activities.	Potential injury during carbon change-out activities. Potential injury when handling muriatic acid.

Note: carbon change-out activities occur at a greater rate for the GAC operation.

An important element of versatility is the ability to treat various COCs. During the field-based pilot testing, the LSTE-10 effectively treated the typical suite of COCs including BTEX, M*t*BE and *t*BA. Conversely, AS is ineffective with *t*BA due to the compound's high solubility in water; the FBR is ineffective with M*t*BE because the microbes preferentially degrade BTEX over oxygenates; and the GAC becomes less effective as concentrations of M*t*BE and *t*BA increase due to the adsorptive properties of carbon. While all four remediation technologies are mobile, the LSTE-10 is the system of choice to quickly begin operations, process potentially impacted groundwater and effectively remediate sites with liquid-phase hydrocarbons.

4.0 FINDINGS

Table 6 summarizes the cost-per-gallon of treated effluent for 1, 2, 5 and 10 years at a flow rate of 10 gpm for each of the technological approaches studied.

TABLE 6: COST PER GALLON OF TREATED WATER

Years of Operation	Low Concentration (3,250 ppb)				Medium Concentration (30,000 ppb)				High Concentration (300,000 ppb)			
	LSTE-10	GAC	FBR	AS	LSTE-10	GAC	FBR	AS	LSTE-10	GAC	FBR	AS
1	$0.035	$0.021	$0.026	$0.022	$0.035	$0.031	$0.026	$0.028	$0.035	$0.055	0.171	0.042
2	0.021	0.018	0.017	0.016	0.021	0.029	0.017	0.022	0.021	0.053	0.113	0.036
5	0.012	0.017	0.012	0.013	0.012	0.027	0.012	0.019	0.012	0.051	0.079	0.033
10	0.009	0.016	0.010	0.012	0.009	0.027	0.010	0.017	0.009	0.051	0.067	0.032

Years of Operation	Free Product (2,300,000 ppb)			
	LSTE-10	GAC	FBR	AS
1	$0.040	NA	NA	$0.064
2	0.024	NA	NA	0.054
5	0.014	NA	NA	0.048
10	0.010	NA	NA	0.046

5.0 SUMMARY AND CONCLUSIONS

A total of nine scenarios were developed in the field-based pilot test. These scenarios focused on two variables: influent flow rate and influent COC concentration. Based on the cost analysis, the LSTE-10 is best suited for sites where long-term operation is expected. Additionally, if both flow rate and concentration are high, LSTE-10 is the most efficient approach.

As the data in Table 6 shows, LSTE-10 becomes more cost competitive as concentrations and flow rates increase, and the longer the term of use. For high concentrations at a flow rate of 10 gpm, the cost for the LSTE-10 drops from $0.035 per gallon during the initial year of operation, to $0.009 per gallon at ten years. The next most cost effective technology under similar conditions is AS, which costs over three times as much per gallon (i.e., $0.032) as the LSTE-10 ($0.009). At ten years, GAC and FBR cost $0.051 per gallon and $0.067 per gallon, respectively.

Further, in the free product scenario, only the LSTE-10 and AS has the ability to operate under these parameters with AS costing over four times ($0.046) as much per gallon as LSTE-10 ($0.010). The GAC and FBR are simply unable to remediate free-product sites.

Of all systems analyzed during this study, the LSTE-10 is capable of effectively remediating the widest range of COC mixtures. Each of the other systems have limitations as to a particular contaminant (*e.g.* GAC and AS do not remove *t*BA; FBR needs a scrubber to eliminate BTEX and cannot maintain high flow rate if concentrations increase, etc.).

From a safety perspective, the maintenance requirements for the LSTE-10 are far less than those for the other technologies, leading to reduced risk of personnel injury.

The LSTE-10 generates the least amount of waste during operation, reducing overall costs.

The LSTE-10's more favorable system-operation time and ability to respond rapidly to excursions in the influent concentrations minimize the potential for plume migration and the resultant increase in potential liability when the system is not operating.