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An Experimental Investigation of Thermal Methods for In-situ Remediation of MTBE-Impacted Groundwater

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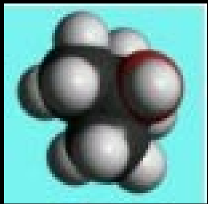
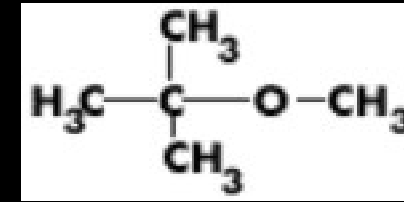
Presentation Outline

- Review of MTBE
- Experiment Objectives
- Experimental Procedure
- Experimental Results
- Implementation of Soil Heating in the Field
- Conclusions.



Properties of MTBE



- MTBE has a high solubility in water. It is ~ 24 times more soluble in water than Benzene (43,000 to 50,000 mg/L).
- MTBE has a high vapor pressure, more than 2½ times greater than the vapor pressure of Benzene at 25 °C. The vapor pressure of MTBE (and BTEX) increases exponentially with temperature.
- MTBE has a low Henry's Law Constant (air-water partitioning coefficient) in comparison to the BTEX components that increases with temperature (more than doubles from 20 to 40 C).
- The biodegradation rate of MTBE is an order of magnitude lower than that of the BTEX fuel components.
- MTBE has a low organic partition coefficient in comparison to BTEX components, reflecting its lesser affinity for soil adsorption.
- MTBE is lower specific gravity than water and a higher vapor density than air
- MTBE has a low taste and odor threshold.

Development of an in-situ remediation strategy for MTBE?

Properties of MTBE & BTEX

Property	MTBE	Benzene	Toluene	Ethylbenzene	Xylene
% Volume in Fuel	15	1	5	<1	8
Water Solubility, [mg/L]	43,000	1,780	535	161	146
Vapor Pressure, [mmHg]	251	95	28	9	8
Henry's Constant	0.020	0.22	0.24	0.35	0.00024
Biodegradation Rate, [%/D]	0.01	0.1-1.0	0.1-1.0	0.1-1.0	0.1-1.0
Adsorption, $\log(K_{oc})$	1.05	1.90	2.0	2.50	2.6
Molecular Weight, [g/mol]	88	76	92	106	106
Specific Gravity	0.74	0.88	0.87	0.87	0.87
Specific Vapor Density	3.80	3.36	3.97	4.57	4.57
Odor Threshold, [ppbv]	95	3,000	160	6,000	20,000
Taste Threshold, [μg/L]	10-130	2,500	na	na	na

Properties of MTBE suggest:

- Might be difficult to remove from the soils using vapor extraction or multi-phase extraction.
- Bio-remediation may not be as effective for remediation of MTBE as for other fuel components.
- Plumes might be relatively larger in extent and remediation may require the pump and treat of huge volumes of groundwater and significant ex-situ treatment.
- Begs the question . . . .

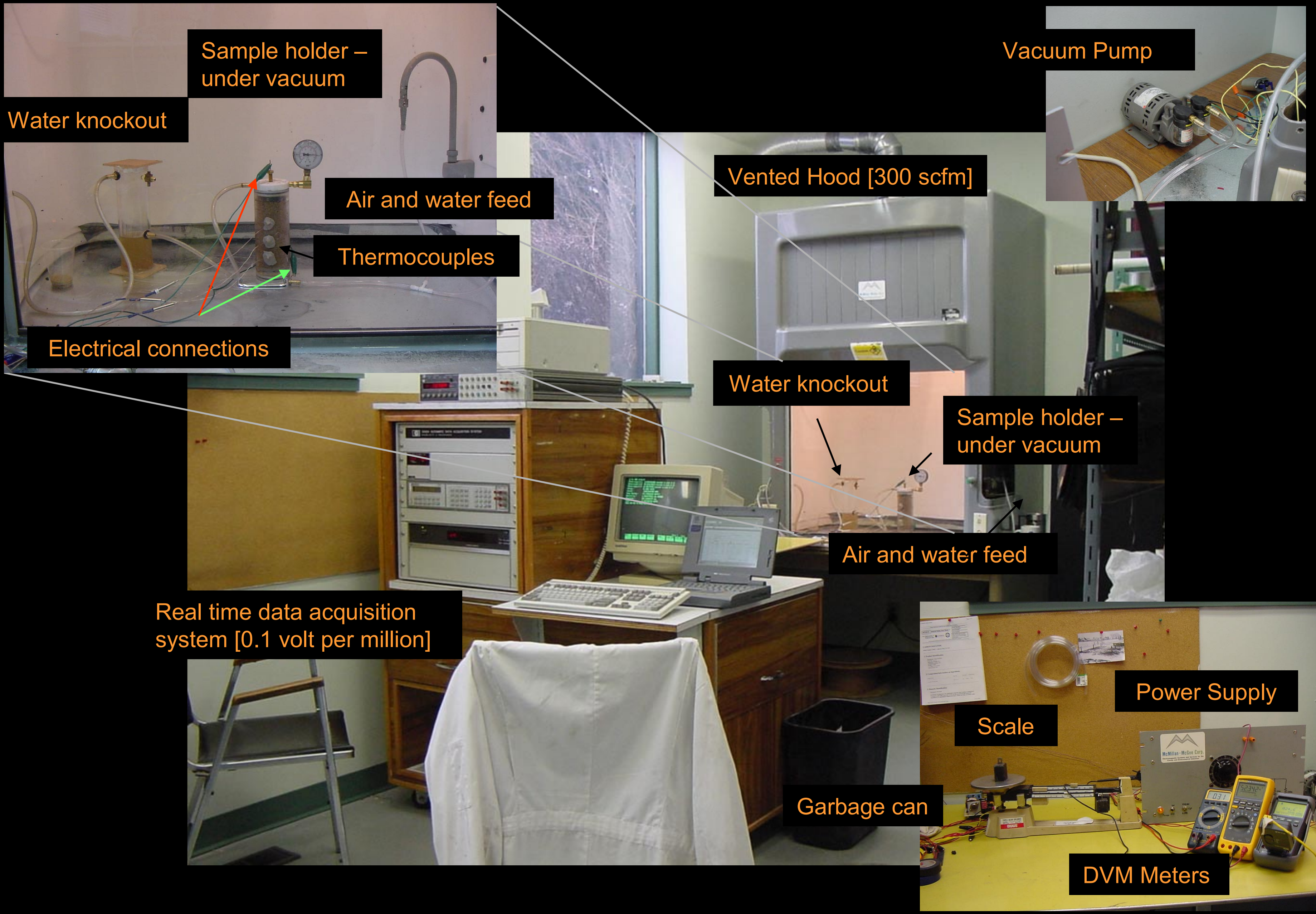
Will Heat Help?

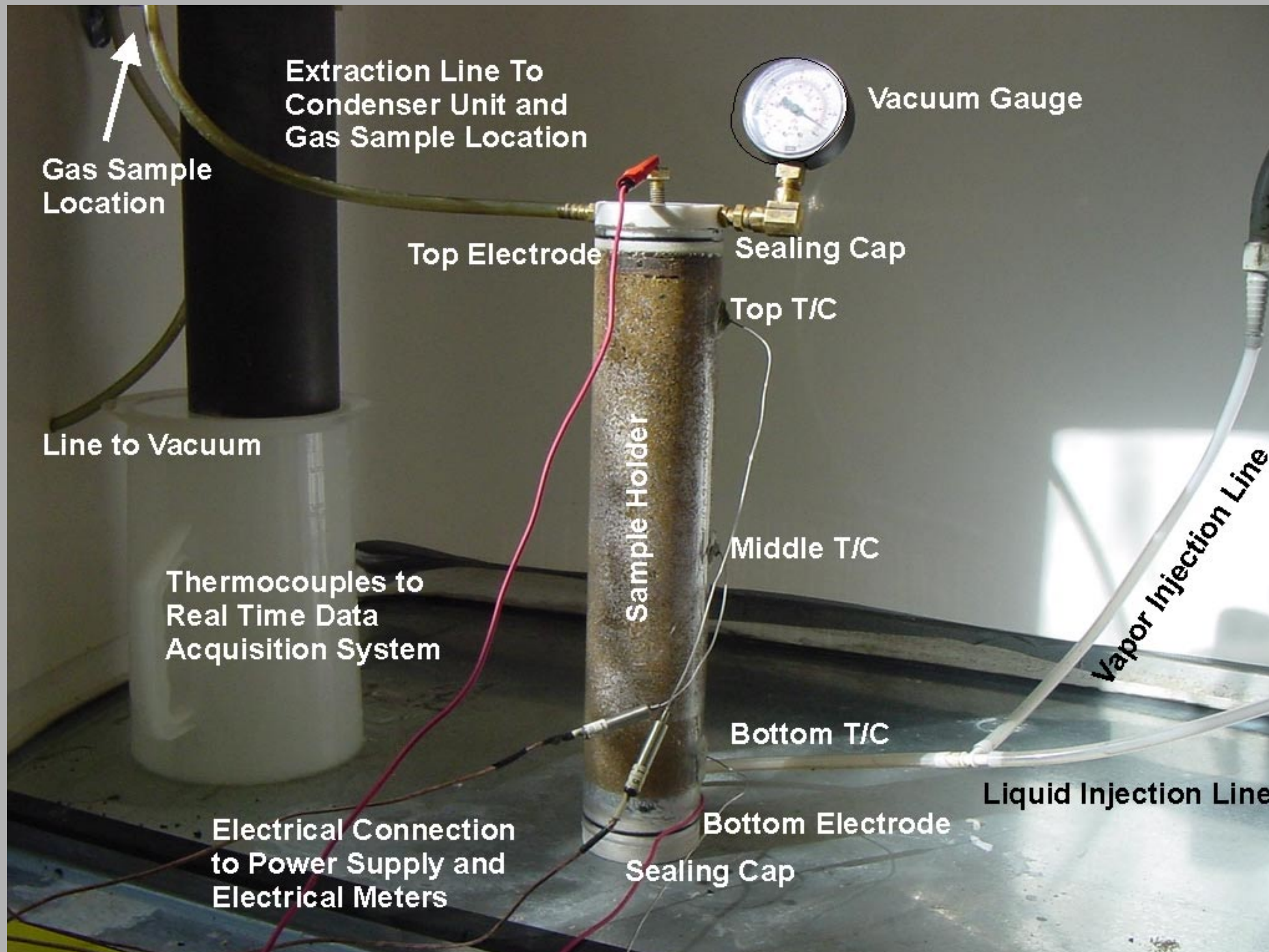
Objective of Experimental Investigation

- Determine whether the addition of heat by the conversion of electrical energy in the porous media enhances the in-situ remediation of MTBE from the water saturated sand, in this case in combination with air sparging and soil vapor extraction.

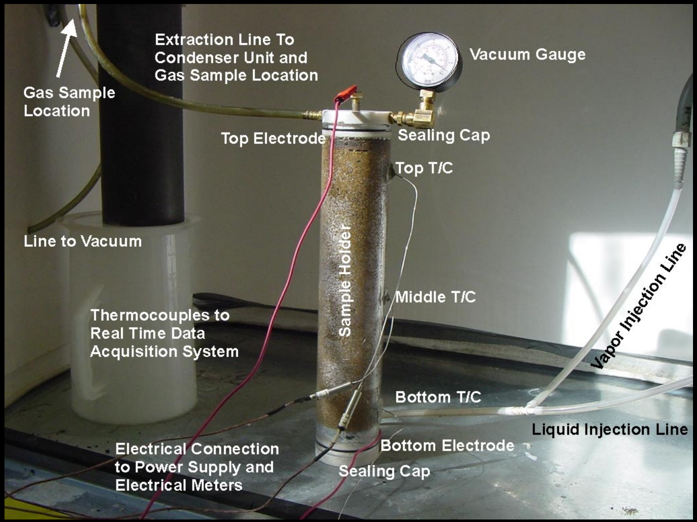
Test the Hypothesis

Heat helps in the remediation of MTBE impacted soils.


Sample holder – under vacuum
Water knockout
Air and water feed
Thermocouples
Electrical connections
Vacuum Pump
Vented Hood [300 scfm]
Water knockout
Sample holder – under vacuum
Air and water feed
Real time data acquisition system [0.1 volt per million]
Power Supply
Scale
Garbage can
DVM Meters


Extraction Line To
Condenser Unit and
Gas Sample Location
Vacuum Gauge
Gas Sample
Location
Top Electrode
Sealing Cap
Top T/C
Line to Vacuum
Sample Holder
Vapor Injection Line
Middle T/C
Thermocouples to
Real Time Data
Acquisition System
Bottom T/C
Liquid Injection Line
Electrical Connection
to Power Supply and
Electrical Meters
Bottom Electrode
Sealing Cap

Animation of the Bench Scale Investigation



Condenser Unit

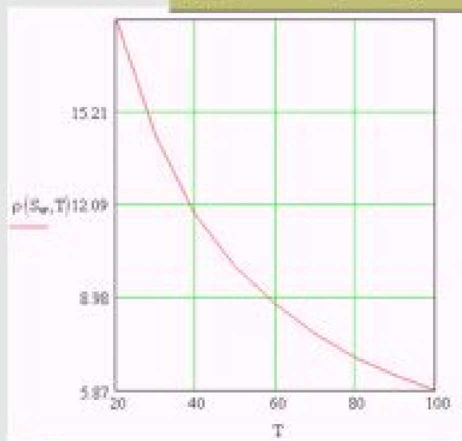
Air Sparging

Electrical Heating and Air Sparging

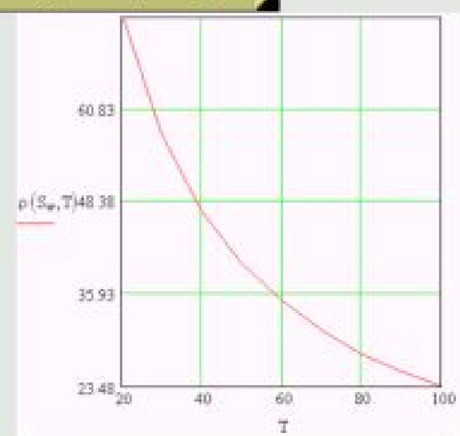
Electrical Heating in the Vadose zone and below the water table since ....

$$\sigma_s(S_w, T) = \left[\sigma_w \frac{\phi^{37}}{P_\phi} \cdot S_w^2 + (1-\phi) \cdot \sigma_r\right] \cdot f(T)$$

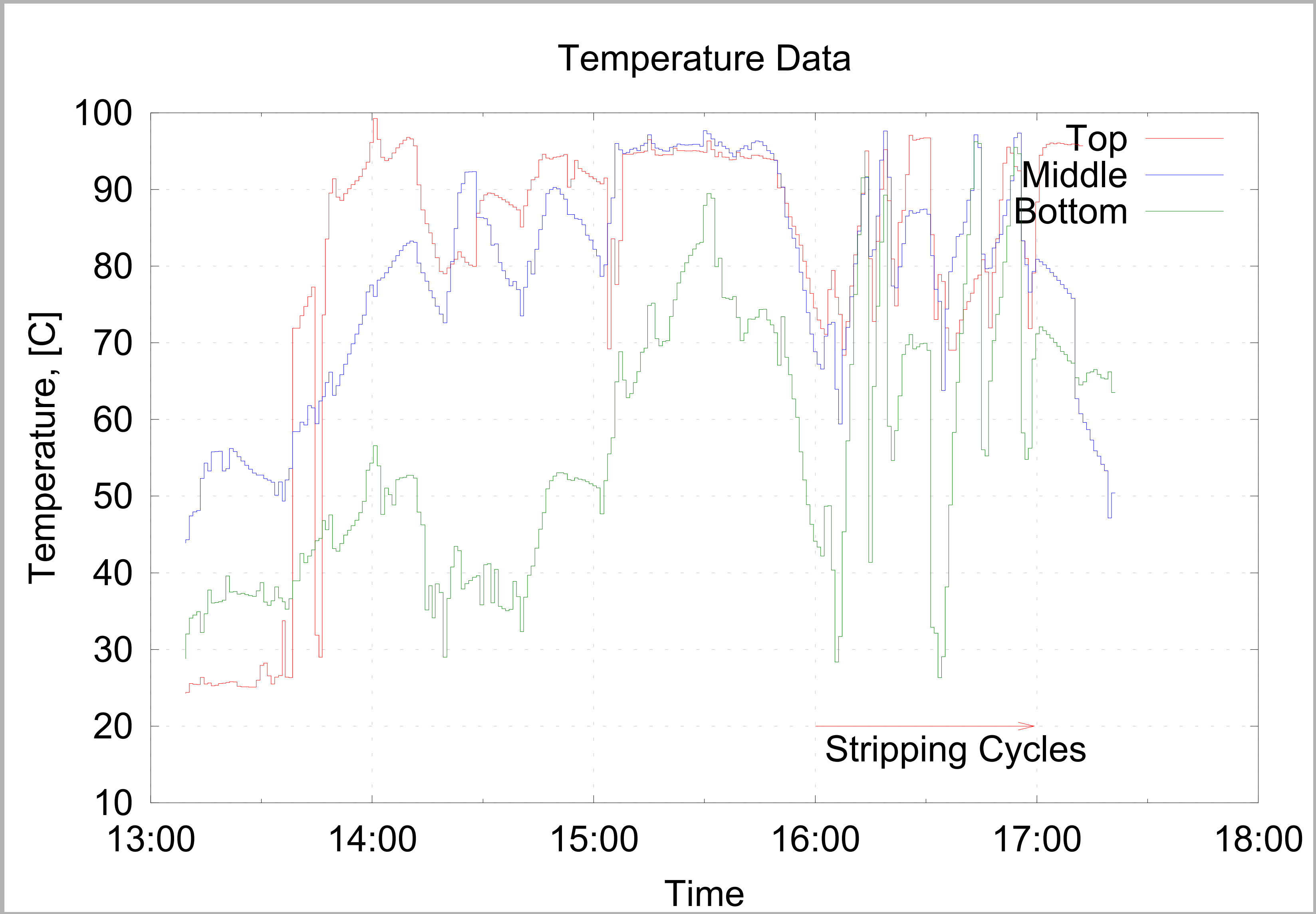
$$f(T) = 1 + b \cdot (T - T_o) + c \cdot (T - T_o)^2 + d \cdot (T - T_o)^3$$

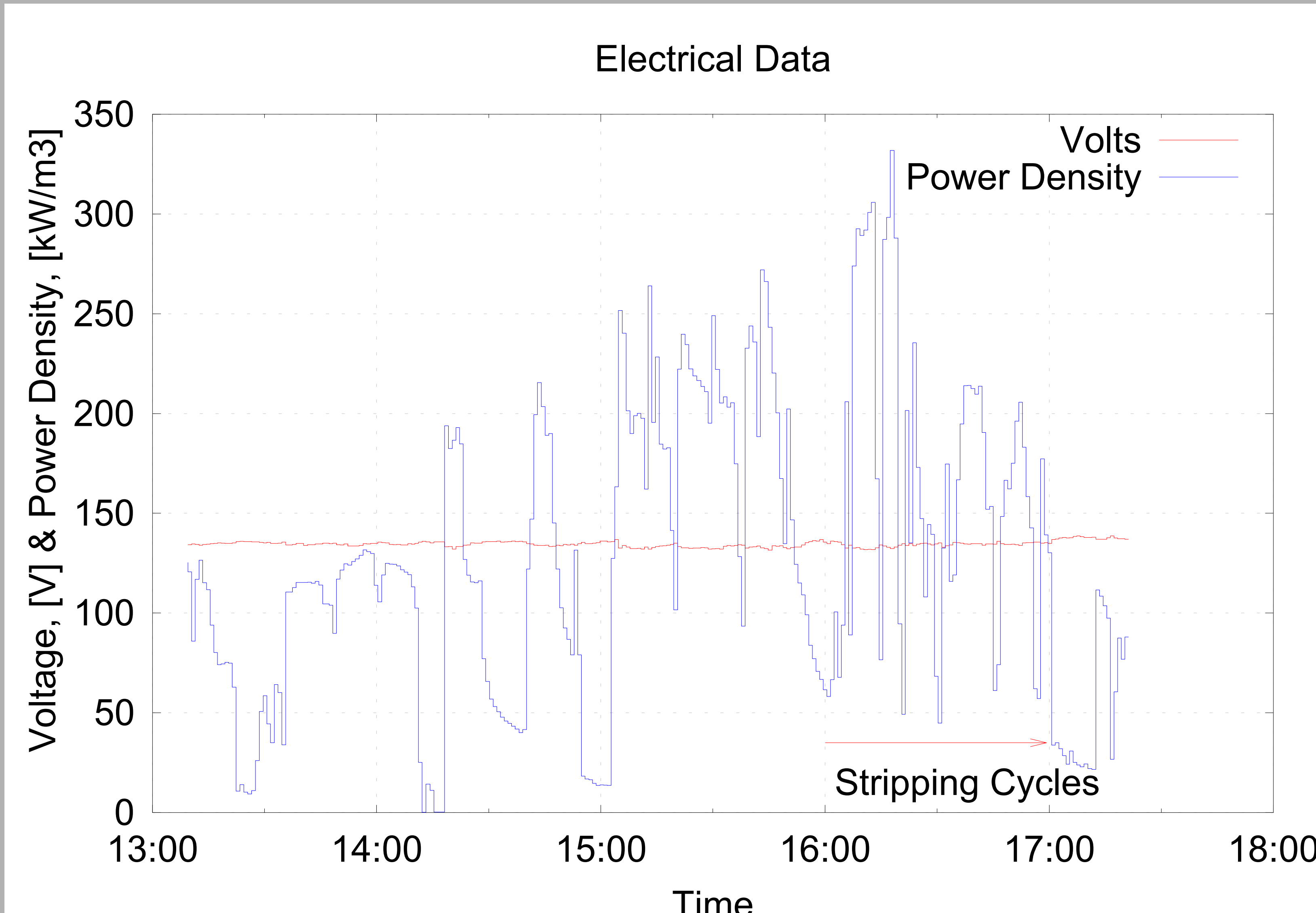


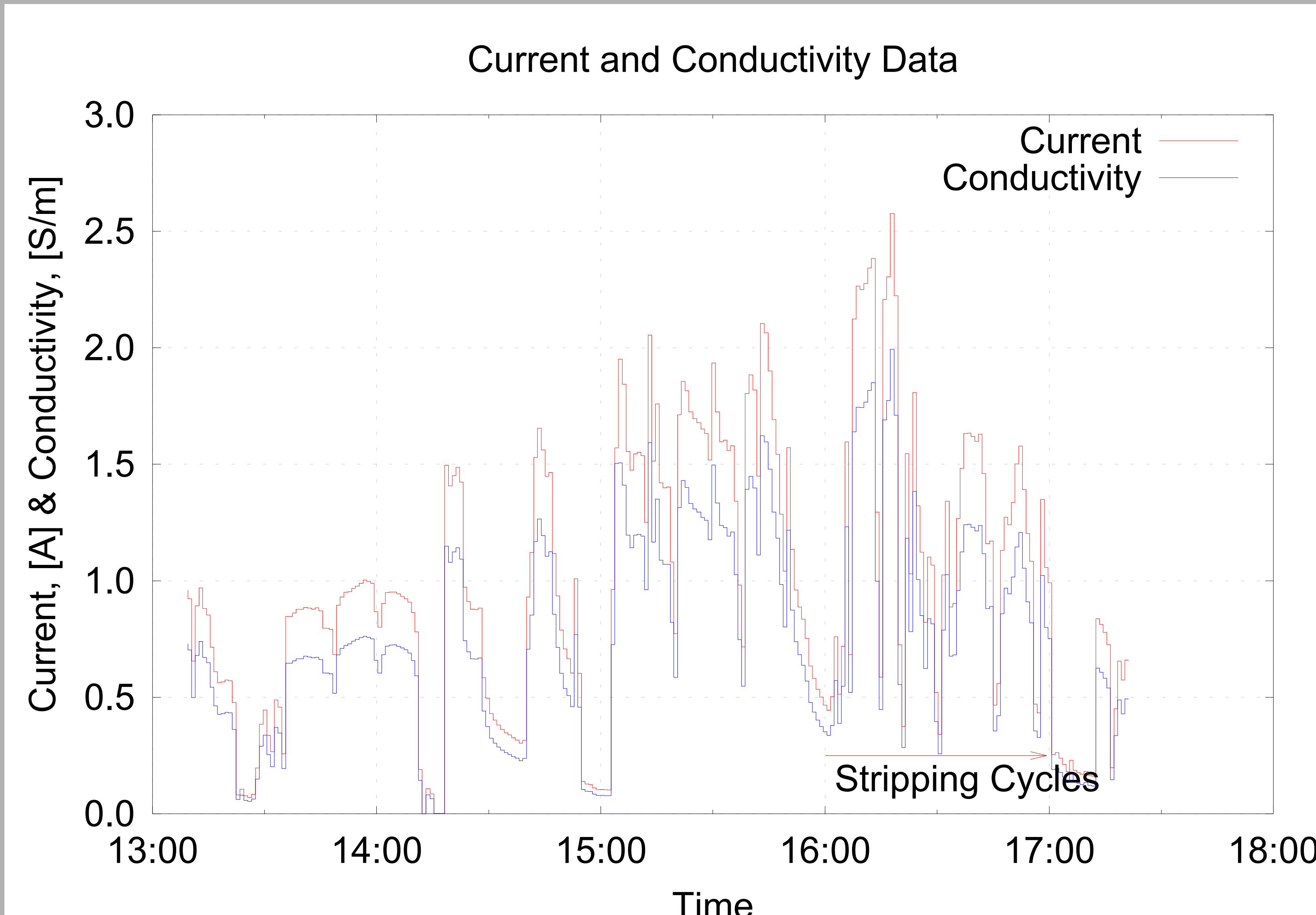
Resistivity of Saturated Zone
Water Saturation is ~100%

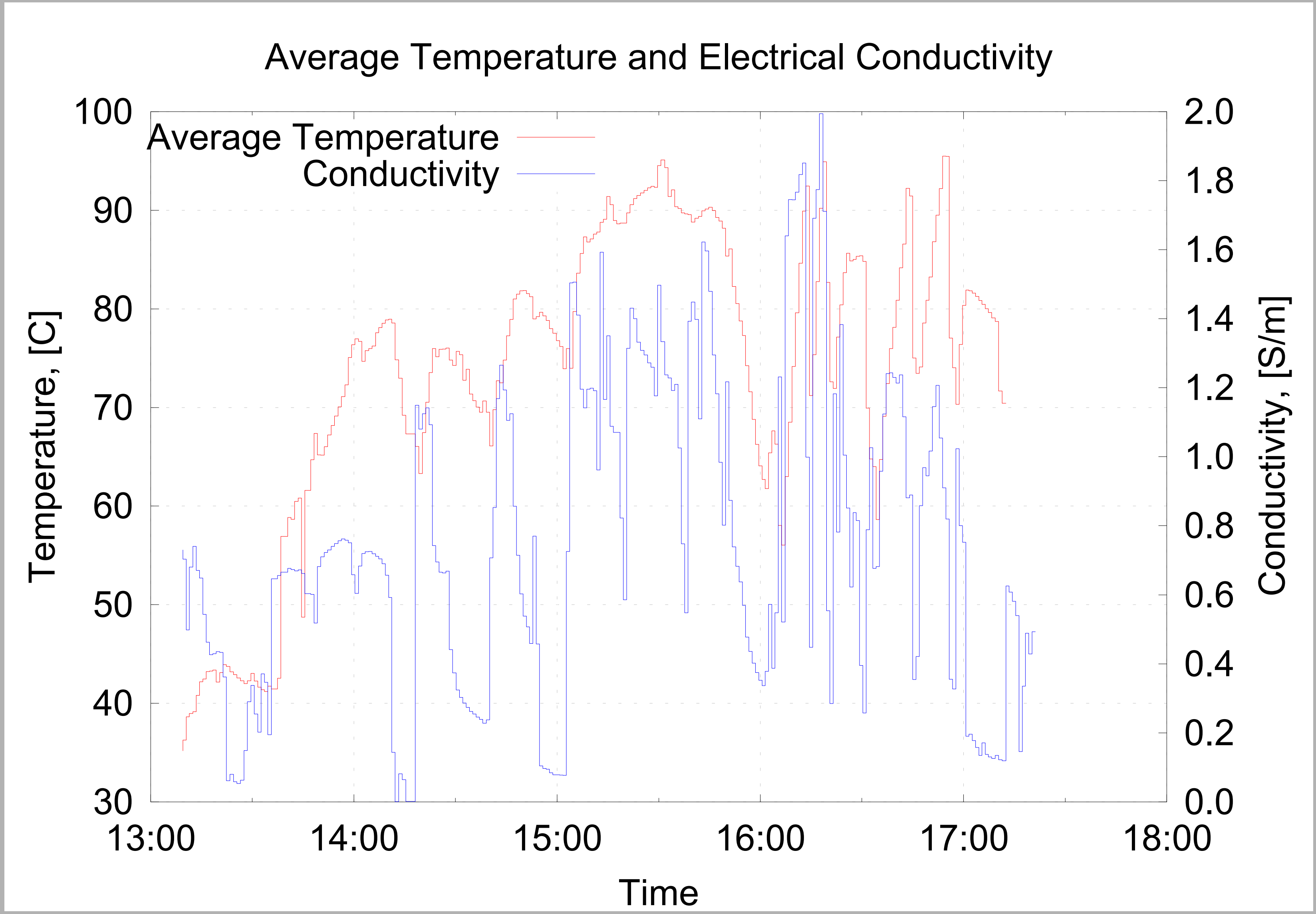


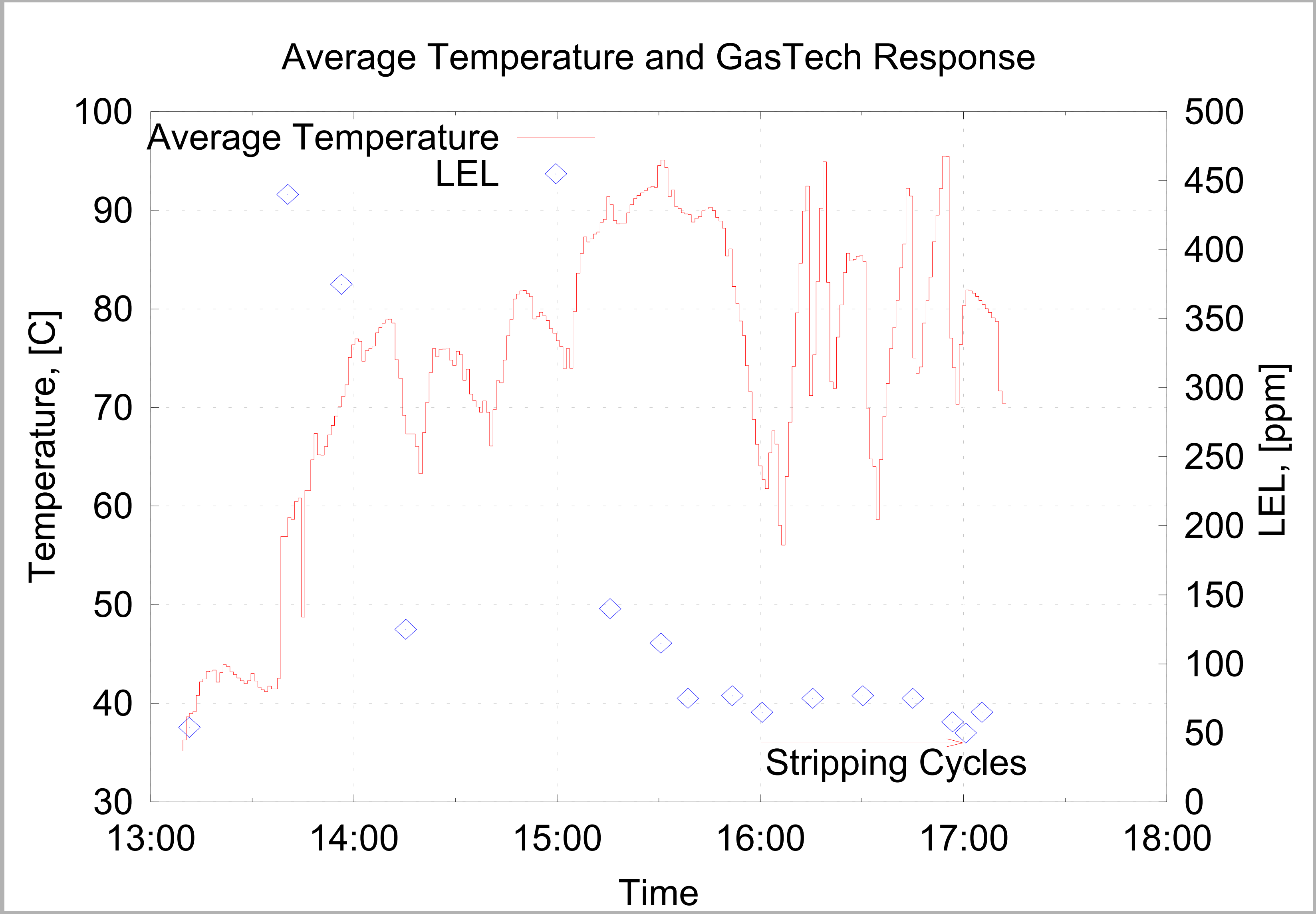
Resistivity of Vadose Zone
Water Saturation is ~ 50%


Temperature Data
100
90
80
70
60
50
40
30
20
10
Temperature, [C]
13:00
14:00
15:00
16:00
17:00
18:00
Time
Top
Middle
Bottom
Stripping Cycles

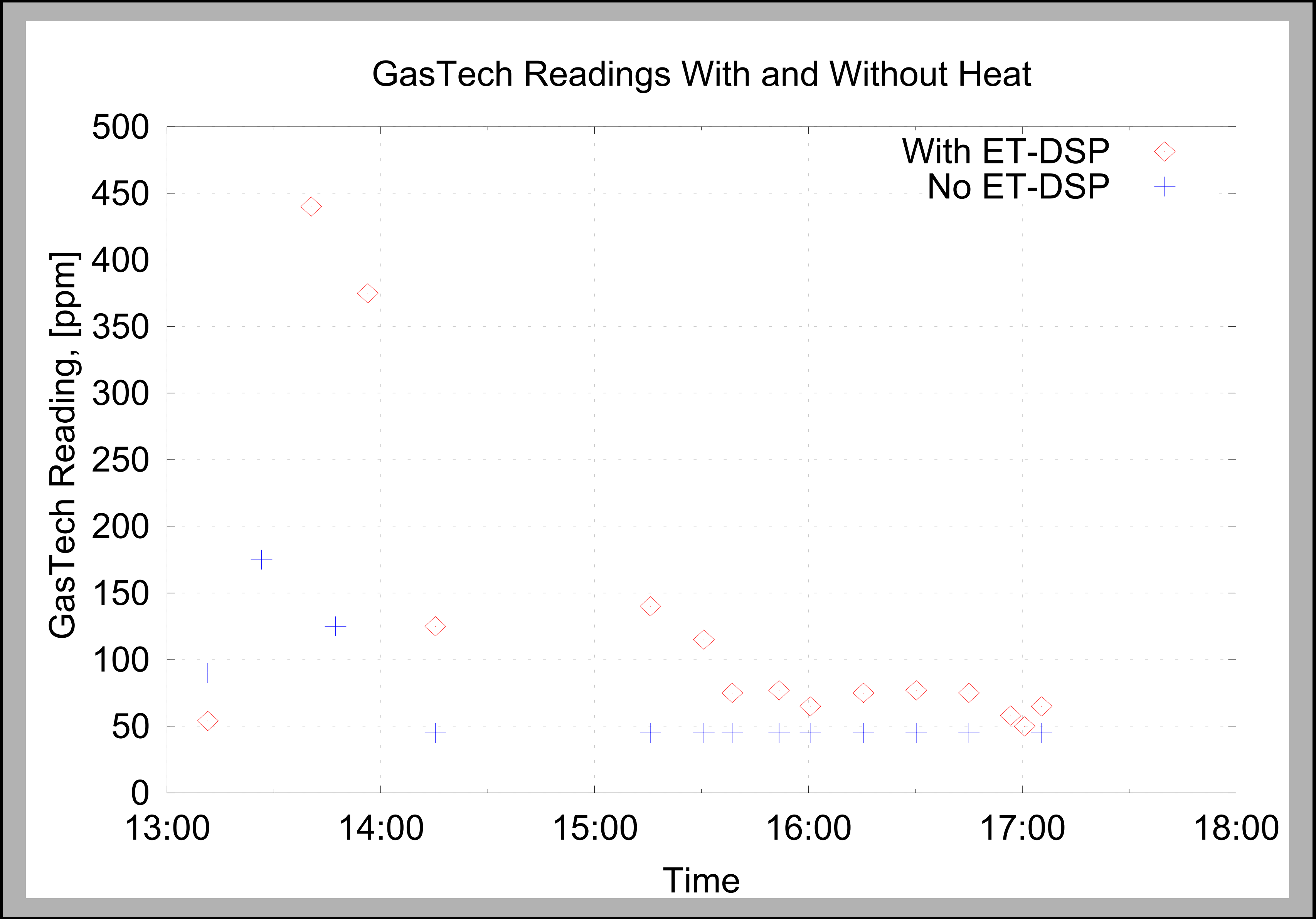

Electrical Data
Volts
Power Density
Voltage, [V] & Power Density, [kW/m3]
350
300
250
200
150
100
50
0
13:00
14:00
15:00
16:00
17:00
18:00
Time
Stripping Cycles


Current and Conductivity Data
Current, [A] & Conductivity, [S/m]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Current
Conductivity
Stripping Cycles
13:00
14:00
15:00
16:00
17:00
18:00
Time


Average Temperature and Electrical Conductivity
Average Temperature
Conductivity
Temperature, [C]
100
90
80
70
60
50
40
30
Conductivity, [S/m]
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
13:00
14:00
15:00
16:00
17:00
18:00
Time



Average Temperature and GasTech Response
Average Temperature
LEL
Temperature, [C]
LEL, [ppm]
Time
Stripping Cycles
100
90
80
70
60
50
40
30
500
450
400
350
300
250
200
150
100
50
0
13:00
14:00
15:00
16:00
17:00
18:00


GasTech Readings With and Without Heat
With ET-DSP
No ET-DSP
GasTech Reading, [ppm]
0
50
100
150
200
250
300
350
400
450
500
13:00
14:00
15:00
16:00
17:00
18:00
Time

Summary of Air Sparging – No Electrical Heating Experiment

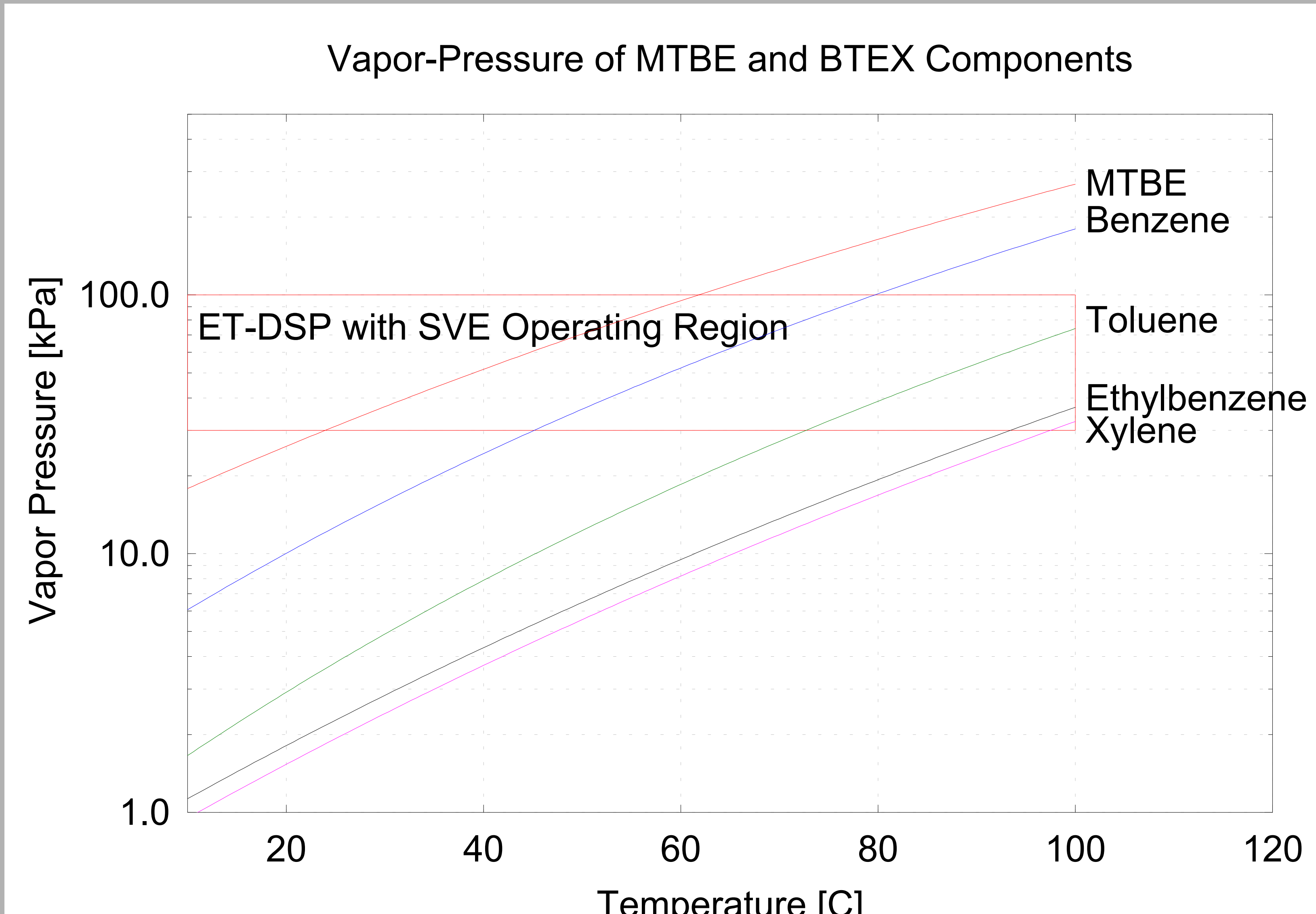
Air Sparging - No Heating Data		
Item	**Data**	**Units**
Inside Diameter	6.33	cm
Outside Diameter	7.65	cm
Length	19.00	cm
Volume	274.46	cm3
Total Sand	1,154.00	grams
Total Water	253.80	grams
Porosity	0.34	fraction
Pore Volume	93.32	cm3
Air Injection Rate	31.94	cm3/s
Air Injection Rate	0.34	PV/s
Duration of Experiment	81,216	seconds
Total PV of Air Injected	27,798	PV

Summary of Air Sparging – With Electrical Heating Experiment

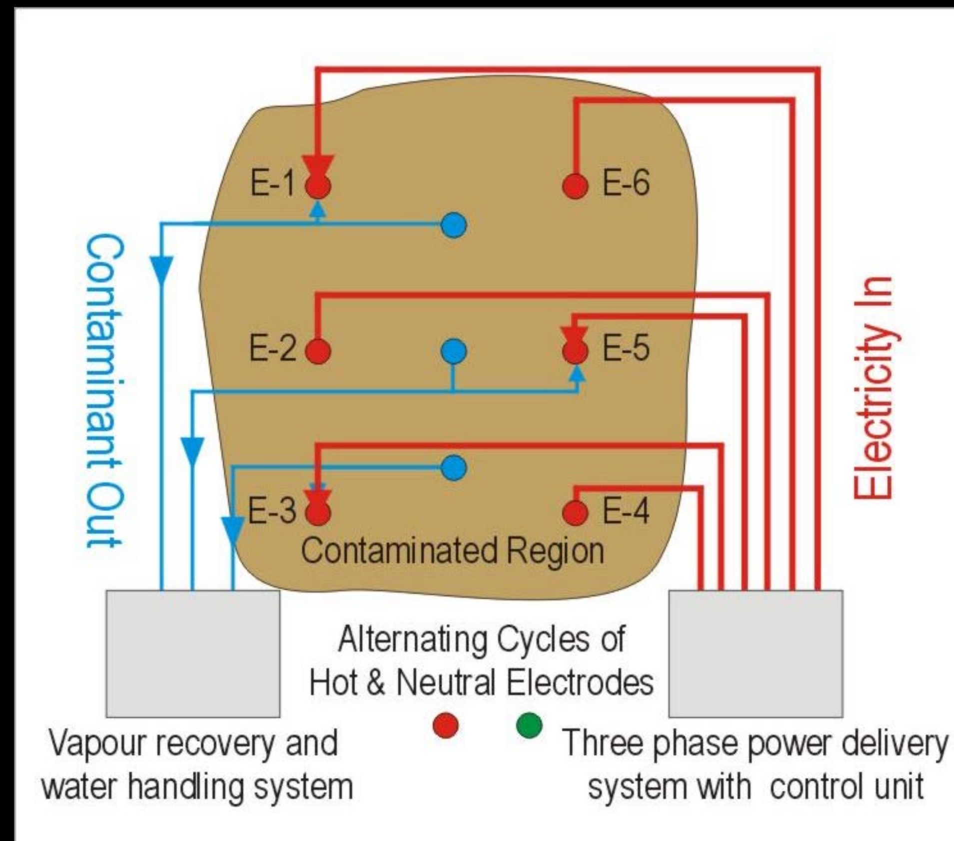
Air Sparging - With Heating Data		
Item	**Data**	**Units**
Inside Diameter	6.33	cm
Outside Diameter	7.65	cm
Length	32.20	cm
Volume	465.14	cm3
Total Sand	1,952.50	grams
Initial Water	423.80	grams
Porosity	0.35	fraction
Pore Volume	162.80	cm3
Air Injection Rate	30.48	cm3/s
Air Injection Rate	0.19	PV/s
Duration of Experiment	16,560	seconds
MTBE Water Added	317.85	grams
Electrolyte Added	84.65	grams
Total PV of Air Injected	3,101	PV
Total Electrical Enegy Injected	384.01	kWhr/m3

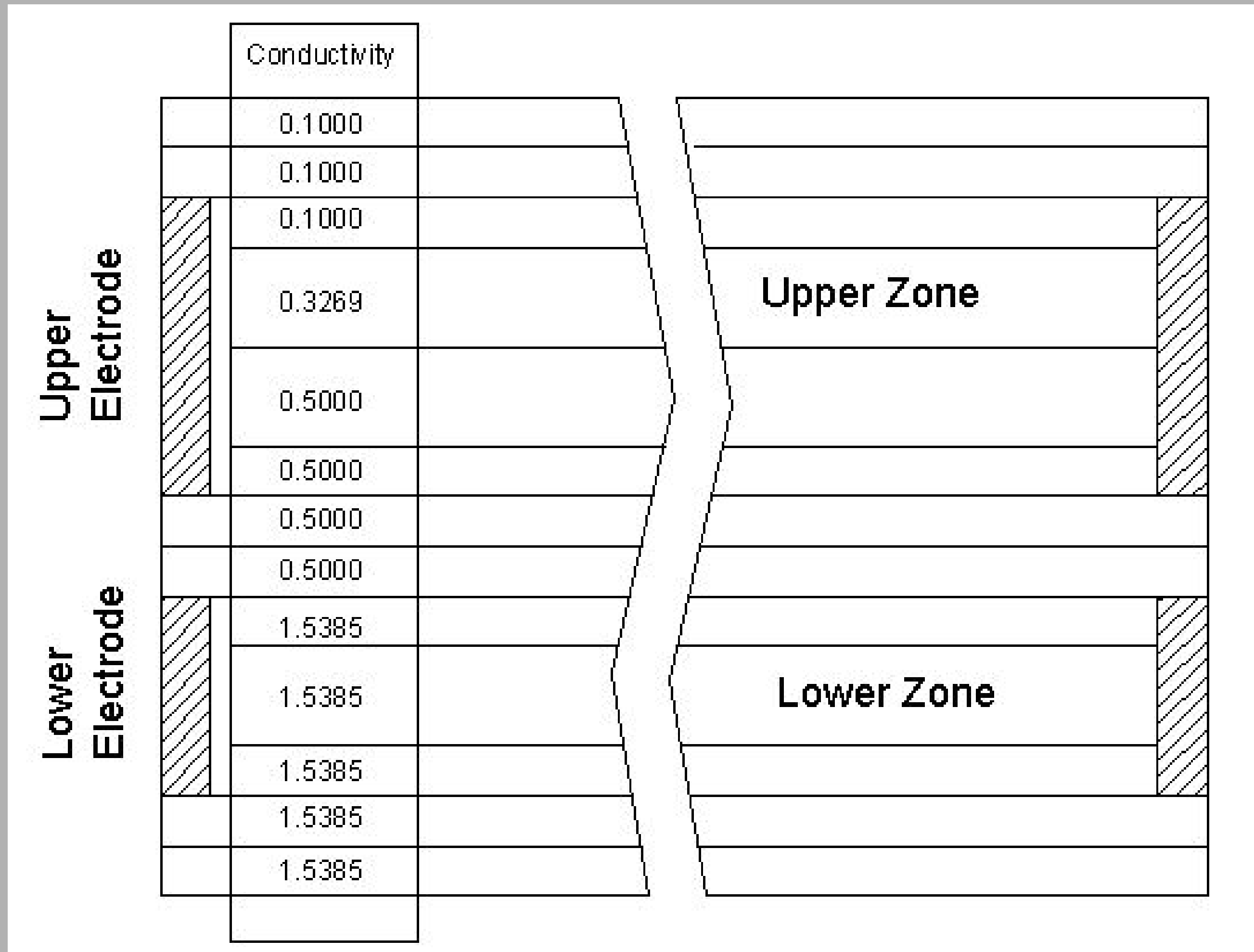
Summary of Experimental Results (cont.)

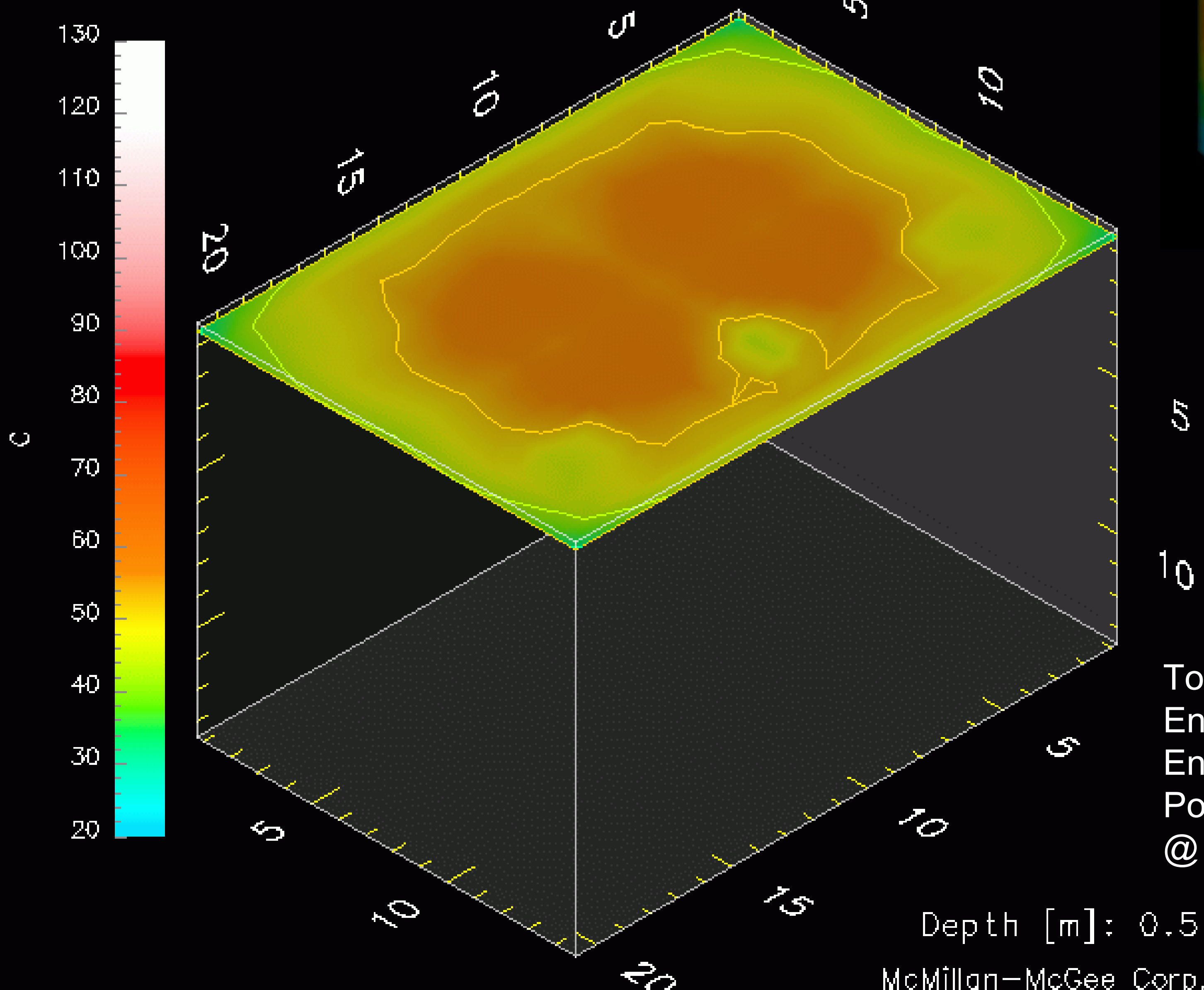
Summary of Laboratory Results	
Results	**Conc. [ppm]**
Initial Concentration of MTBE by Volume	311
Initial Measured Concentration of MTBE	43.4
Concentration of MTBE after Air Sparging-No Heating	1.40
Concentration of MTBE after Air Sparging- With Heating	0.005
Adjusted for injected electrolyte	0.006
Note that laboratory ND level is 5 ppb	

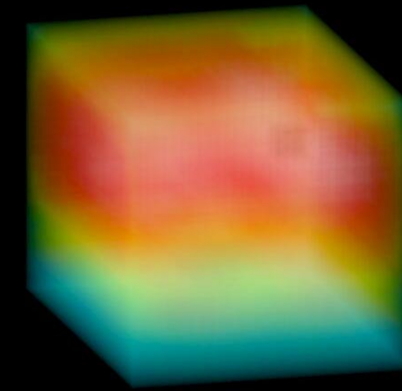

Vapor-Pressure of MTBE and BTEX Components
Vapor Pressure [kPa]
100.0
10.0
1.0
20
40
60
80
100
120
Temperature [C]
ET-DSP with SVE Operating Region
MTBE
Benzene
Toluene
Ethylbenzene
Xylene

Electro-Thermal Dynamic Stripping Process An Electrical Soil Heating Technology




Conductivity
0.1000
0.1000
0.1000
0.3269
0.5000
0.5000
0.5000
0.5000
1.5385
1.5385
1.5385
1.5385
1.5385
Upper Electrode
Lower Electrode
Upper Zone
Lower Zone





Total Volume: 4,150 m3
Energy: 547,000 kWhr
Energy: 132 kWhr/m3
Power Cost: $7.91/m3
@ $US0.06 per kWhr

Conclusions

Heat Helps in the Remediation of MTBE