THERMAL TREATMENT – HOW MUCH ENERGY DOES IT TAKE?

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Background & Objectives

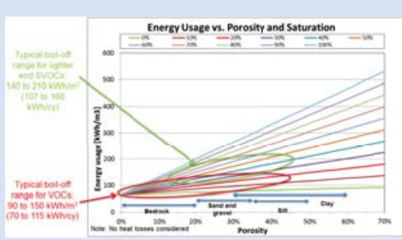
Thermal Conductive Heating (TCH), Electrical Resistance Heating (ERH) and Steam Enhanced Extraction (SEE) are widely used thermal technologies capable of effectively remediating a variety of chemicals from different geological settings, ranging from tight clays to permeable sands. During thermal applications, the energy needed to reach project goals, is one of the major resources that contributes to the environmental footprint and cost associated with implementing these thermal technologies.

It is crucial that sufficient energy is delivered to the subsurface to overcome site heat demands, balance heat losses, and to facilitate enough boiling and steam stripping to meet remedial objectives.
This study focused on a detailed analysis of these energy needs.

Factors Governing Energy Usage

Various factors govern the energy usage during thermal remedies. The following major site specific factors contribute to the total site energy usage:

- Porosity and saturation determine the subsurface heat capacity and therefore the energy needed to increase the temperature and boil off pore water.
- The size and shape of the treatment zone and local groundwater flow.
- The influence of the volatilization and mobility of the target contaminants with temperature and associated changes in chemical properties with temperature.
- The thermal design and heating technology applied.
- The numeric remedy goals and exit strategy.
- The theoretical energy usage from a 100°C application is shown below as a function of soil porosity and initial saturation:



Contaminant Characteristics Effect Energy Usage

Site contaminant characteristics effect the energy usage:

- Boiling Point
- Solubility
- Henry's Law constant
- Vapor Pressure
- Hydrolysis Rate with Temperature

Compound	Boiling Point (°C)	Solubility (mg/l)	Henry's Law	100°C V.P. (atm)	Target at 100 °C?
vinyl chloride	-14	1	1.083	30.47	Easy
Freon 113	48	170	13.038	4.94	
1,1-DCE	32	2,600	1.059	7.36	
trans 1,2-DCE	48	600	0.386	5.03	
methylene chloride	41	20,000	0.121	6.42	
cis 1,2-DCE	60	800	0.186	3.35	
1,1-DCA	57	5,500	0.255	3.78	
chloroform	62	8,000	0.172	3.00	
gasoline	100	120		1.09	
benzene	80	1,780	0.216	1.78	
1,1,1-TCA	74	4,400	0.711	2.10	
TCE	87	1,100	0.417	1.48	
1,2-DCA	84	8,690	0.068	1.76	
tert butyl alcohol	83	43,000		1.96	
1,2-dichloropropane	97	2,700	0.096	1.09	
toluene	111	515	0.262	0.73	
PCE	121	150	0.699	0.53	
ethylbenzene	136	152	0.322	0.34	Medium
1,1,2-TCA	114	4,500	0.037	0.66	
chlorobenzene	132	500	0.147	0.38	
xylene	140	180	0.250	0.28	
1,2,4-trimethylbenzene	169	57		0.12	
1,1,2,2-teCA	146	2,900	0.010	0.24	
chlorotoluene	160	377	0.023	0.15	
bromoform	151	3,190		0.22	
1,4-dichlorobenzene	173	49	0.064	0.09	
JP-4	180	20		0.08	
1,2,3-trichloropropane	156	1,900	0.008	0.15	Difficult
1,2-dichlorobenzene	179	100	0.064	0.08	
dibromochloropropane	195	1,230		0.12	
Jet A / JP-8	205	10		0.04	
hexachloroethane	185.6	50	0.341	0.05	
trichlorobenzene	213	19	0.078	0.03	
naphthalene	218	30	0.028	0.03	
JP-5	225	8		0.02	
diesel	300	5		0.00	

Data from Over 60 Thermal Projects

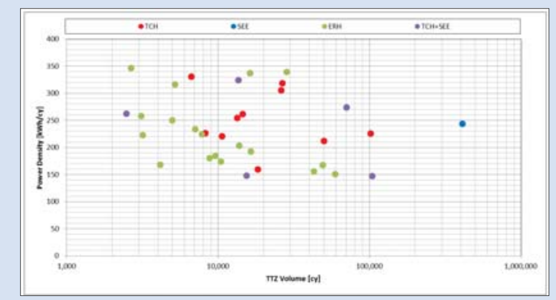
Data compiled by looking at project data from 64 ERH, TCH, SEE and combined technology thermal sites.

Large data set is needed because of the site-specific variability related to groundwater flux, contaminant mixtures, starting concentrations, and treatment goals.

All data were derived from projects with a target treatment temperature of 100°C.

Thermal Technology	Number of Sites
ERH	30
SEE	2
TCH	26
Combined TCH & SEE	6
Total Sites	64

The energy usage per volume treated were analyzed. The figure below shows the power density for the sites evaluated.



	n [-]	Min [kWh/cy]	Max [kWh/cy]	Average [kWh/cy]
ERH	18	151	347	228
SEE	1			244
TCH	10	159	331	251
TCH+SEE	5	147	324	231

Average power densities between 228 and 251 kWh/cy

Power Usage vs. Contaminant

Lighter end SVOCs require more energy to be properly removed in a 100 °C application. Therefore, a longer treatment duration and higher power input is required.

Heat Losses

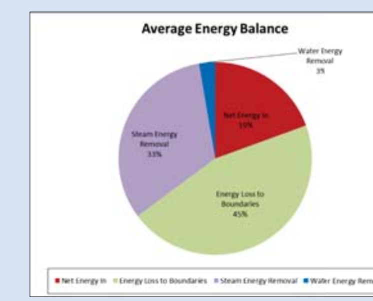
The following energy streams are typically monitored during a thermal remediation project:

- Energy injected by the chosen technology
- Energy extracted as steam
- Energy extracted as hot water
- Energy extracted as hot air
- Cooling water/drip system for electrodes (ERH only)

Unknown energy streams:

- Heat loss to surroundings by thermal conductive heating or any local convective heat transport
- Heat loss in groundwater leaving the site

Data from 7 projects shows that heat losses can be substantial:



Conclusions

- Datasets indicate a big differential on power usage – even within the same technology for the same contaminants. Site specific conditions affect energy usage.
- While a theoretical calculation shows that 70-115 kWh/cy typically will be required to meet treatment goals for VOCs, actual site data indicate that 228 to 251 kWh/cy are typically required in reality.
- Typical lighter end SVOCs require ~30% more energy to meet performance goals, compared to VOCs.
- The TCH technology requires slightly more energy than ERH (~10%), but typically achieves lower post-treatment concentrations (better treatment closer to heater borings).
- Heat losses can be substantial – need to be properly evaluated for all sites.
- Benefit from hydrolysis and thermally enhanced bio remediation should be considered where possible, to reduce the overall energy usage.