

CVEN 4474/5474 Haz Waste Outline

- Site Clean-up Methods:
- I. In-Situ Vadose Zone Soil
 - Soil Vapor Extraction
 - Thermal desorption

Soil Vapor Extraction

- Remediate vadose zone soil *in situ*
- Effective for volatile organic compounds
- General description:
 - Install a well screened in the vadose zone
 - Pull a vacuum on the well to remove contaminated soil vapor
 - Treat the extracted gas

Example SVE problem

Given a site contaminated with benzene from a surface spill. The groundwater table is ~30' deep in sandy soil. Soil is contaminated down to the water table.

Should SVE be used?

- 1) Benzene: $H' \sim 0.23$ @ $20^\circ\text{C} > 0.01$ ok
vap pr 95 mm Hg @ $25^\circ\text{C} > 1$ mm Hg ok

Benzene example cont.

- 2) Soil conditions ok?

Field test at $Q_g = 500 \text{ cm}^3/\text{sec}$ in well 2" dia screened 5' to 20' bgs and monitor at 5' away

Plot pres in mm Hg vs ln time

$$k_a = Q_a \mu_a / 4p \text{ b slope}$$

$$k_a = \frac{500 \text{ cm}^3/\text{sec} * 0.18 \text{ mg/cm}^3}{4p(457 \text{ cm})(20,000 \text{ mg/cm}^3 \text{ s}^2)} = 8 \times 10^{-7} \text{ cm}^2$$

$$K_a = k_a \rho_a g / \mu_a$$

$$K_a = 8 \times 10^{-7} \text{ cm}^2 (1.19 \text{ mg/cm}^3) (981 \text{ cm/s}^2) / 0.18 \text{ mg/cm}^3$$

$$K_a = 5 \times 10^{-3} \text{ cm/s} > 1 \times 10^{-3} \text{ ok}$$

Benzene example cont.

- 3) If field test @ 10% water saturation, what is K_a at 20% water saturation?

$$K_a = K_r K_i \text{ where } K_i = \text{"intrinsic"} \text{ for } S = S_r$$

where S_r = residual saturation

$$K_r = (1 - S_e)^2 (1 - S_e^{2/\lambda}) \text{ where } \lambda \text{ soil property, } \sim 3$$

K_r can range from 0 (100% water sat) to 1 (@ $S = S_r$)

$$S_e = \frac{S - S_r}{1 - S_r}$$

$$\text{If } S_r = 3\%, \text{ then } S_e \text{ initial} = (0.1 - 0.03) / (1 - 0.03) = \sim 0.07$$

$$\text{Relative conductivity, } K_r = (1 - 0.07)^2 (1 - 0.07^{5/3}) = 0.85$$

$$K_a = K_r K_i \text{ so } 5 \text{ E-3 cm/s} = 0.85 K_i$$

$$K_i = 6 \text{ E-3 cm/s}$$

$$\text{Then @ 20\% saturation: } S_e = 0.18; K_r = 0.63$$

$$K_a = 0.63(6 \text{ E-3 cm/s}) = 4 \text{ E-3 cm/s}$$

Benzene example cont.

- 4) What is the radius of influence of an extraction well operating in soil at 10% saturation

Assume the steady -state head of air at a monitoring well 5' away was 100 cm

$$s = Q_a \ln(R_i/r) / 2pb'K_a$$

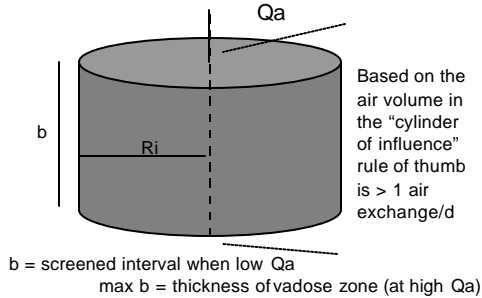
$$100 \text{ cm} = 500 \text{ cm}^3/\text{s} \ln(R_i/5') / 2p(457 \text{ cm})(5 \text{ E-3 cm/s})$$

$$\ln(R_i/r) = 2.87; R_i = 88 \text{ ft} (26.8 \text{ m})$$

If small Q , b = screen interval (assumes air flow parallel to screen)

If large Q , b' = vadose thick. (assumes air drawn from the entire vadose zone)

Cartoon "radius of influence"



Benzene example cont.

5) What flowrate should the well be operated at to achieve the recommended pore volumes of air exchange per day? (@ 10% Sw)

$$\text{Pore volume} = V_a = \eta_a p (R_i)^2 b'$$

$$= (0.9)(0.4)p (26.8 \text{ m})^2 (30') = 7428 \text{ m}^3$$

$$Q_a = 1 \text{ pore vol/d} = 7428 \text{ m}^3/\text{d} = 86,000 \text{ cm}^3/\text{s}$$

6) What vacuum at the extraction well is needed?

$$s = Q_a \ln(R_i/r) / 2pb'K_a$$

Same eqn, with r = well rad.
 $s = 8.6E4 \text{ cm}^3/\text{s} \ln(26.8\text{m}/1\text{m})$ large Q , b' = vadose thick.
 $2p (30') 5E-3 \text{ cm/s}$ Convert units & do math
 $s = 378 \text{ m air head} = 0.04 \text{ atm}$

...may alternatively operate well with a smaller R_i

Benzene example cont.

7) If a site is remediated using SVE how long will the SVE system need to operate?

assume that longterm vapor extraction maintains ~10% equilibrium concentration in extracted gas

Soil initially 5% benzene NAPL saturated, 5% water sat., and equilibrium sorbed to soil, in air, and in water

$$C_a \text{ eq} = \text{Vap } pR/RT = 330 \text{ mg/L} \rightarrow 119 \text{ mg B/L soil}$$

$$C_w \text{ eq} = \text{sol} = 1500 \text{ mg/L} \rightarrow 30 \text{ mg B/L soil}$$

$$C_s \text{ eq} = \text{foc } K_{oc} C_w = 2490 \text{ mg/kg} \rightarrow 4.0 \text{ g B/L soil}$$

$$C_{\text{NAPL}} = 0.05(0.4)\text{ml B/ml soil} * 0.87 \text{ g/mL} = 17.4 \text{ g B/L soil}$$

TOTAL 21.5 g B/L soil

Benzene example cont.

7) how long will the SVE system need to operate?

Mass balance: mass in = mass out

$$C_t * V_t = Q_a C_a t$$

$$21.5 \text{ g B/L soil} * p(27 \text{ m})^2(30') = 7430 \text{ m}^3/\text{d}(0.1)(330 \text{ mg/L})t$$

$$4.5 E8 \text{ g B} = 2.46 E5 \text{ g B/d} * t$$

$$t = 1829 \text{ days} = 5 \text{ yrs}$$

In reality, there will be tailing since the air conc in equilibrium will decrease after the NAPL is gone
 Time until NAPL gone = $17.4 \text{ g/L } p(27 \text{ m})^2(30') / 2.5E5 \text{ gB/d}$
 Time until NAPL gone = 4.06 yrs
 THEN compute decrease in C_a over time...

Benzene example cont.

7) If a site is remediated using SVE how long will the SVE system need to operate?

Mass balance: mass in = mass out

$$C_t * V_t = Q_a C_a t$$

$$C_t = C_a V_a + C_w V_w + C_s M_s$$

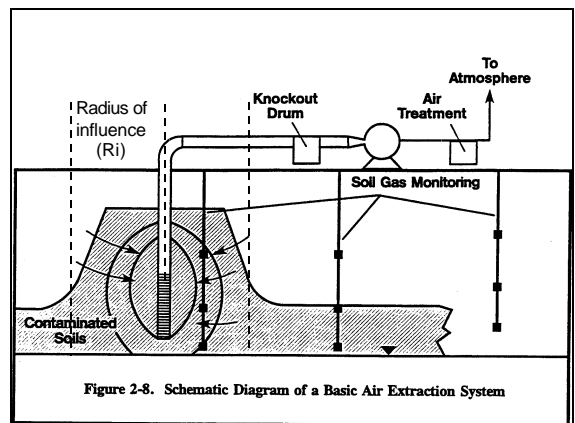
$$C_t = 0.1 H' C_w V_a + C_w V_w + \text{foc } K_{oc} C_w M_s$$

Then can compute decrease in B mass in soil over a time increment: example: 30 days

$$C_t V_t - (2.46 E5 \text{ g B/d} * 30 \text{ days}) = \text{new mass B}$$

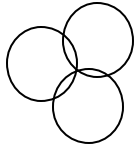
$$8.46E7 \text{ g B} - 7.38E6 = 7.72E7 \text{ g B}$$

Given this new mass, compute C_t , then new C_w ... new C_a
 Then have a new mass extraction rate by the SVE system since the C_a is now lower....
 Continue incrementally, until achieve mass removal

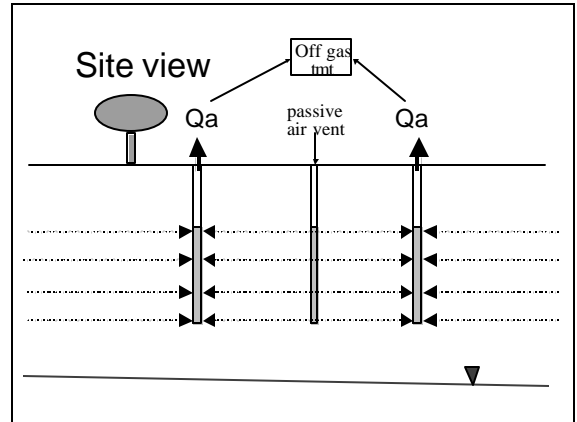


Plan view of site to be remediated by SVE

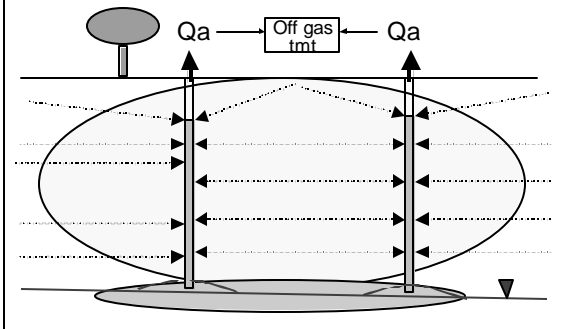
Requiring more than 1 SVE well:



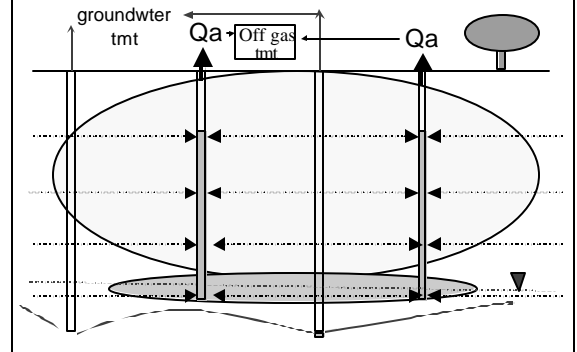
Overlap well radius of influence
What about dead zones?



Optimal use of SVE when LNAPL contamination at the water table = ?
If screen to water table, vacuum will draw water into well



Therefore, use groundwater pumping to lower the water table.
SVE is generally faster than pump and treat.



Thermal Desorption

- Heat the soil to volatilize contaminants, collect contaminated off-gas, and treat
- Can remove organics including PAHs, PCBs, pesticides, dioxins,...
- Can excavate soil and treat on site or off site
 - Pretreat to achieve size <1 inch, <15% moisture
 - Temp: 150-400°C or 400-650°C; ~20 min ret.
 - Typical 20-40 tons/hr processing rate
 - Off gas tmt typically condenser &/or activated carbon
- In situ
 - Heat by electrical resistance, radio frequency, steam
 - Heat to ~100-200°C over 7-20 days
 - Use SVE system to extract & treat contaminated gas