Heat Loss During In Situ Thermal – How to Predict It Using Heatwave

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The power and energy needed for in situ thermal remediation is important for both cost and environmental impacts. Competitive bids encourage thermal vendors to provide optimistic estimates to seem more competitive. Different assumptions are made for the power and energy needed to achieve a certain result, sometimes resulting in designs which underestimate the need.

One of the factors controlling this is the estimate of heat losses. This paper presents the complexities of getting the heat loss calculation right and explains why it is important to use a numerical model rather than a straight percentage. At some sites, the heat losses may equal or exceed the energy needed to raise the temperature and create the boiling required to remove the contaminants.

TRS Group uses a simple numerical model “Heatwave” which uses first principles and keeps track of mass and energy during a remedy. This model has been calibrated to several field sites and is the basis for our energy budgets and estimated durations.

Soils and sediments have different heat capacity

Figure 1 shows the energy density (amount of energy per unit volume) required to raise the temperature from 10 to 100 C for solids with varying porosity and water content.

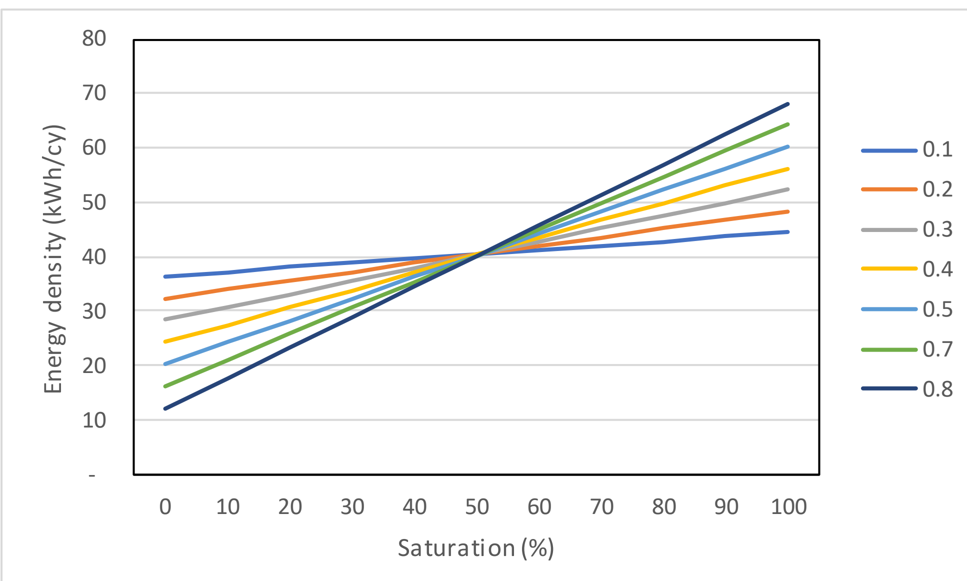

Figure 1. Energy density required to raise the temperature 90°C for soils with different porosities. Heat losses are not included. Solid grain density of 2.65 g/mL is assumed (as quartz).

For many sites, the starting water content isn’t that well known. This means that even the basic energy density is uncertain. If the saturation is close to 50%, this uncertainty is less important. But wet areas of a site may need as much as double the energy to heat up, compared to dry zones. Treatment zones which straddle the water table may have different energy needs from top to bottom.

The heat losses can be significant and cannot be ignored

An energy balance for an example site is provided in Figure 2. Note that the heat losses amount to approximately 30% of the total energy delivered. Another 35% is extracted in the steam produced by boiling in the subsurface. As a result, the energy used for the remedy is close to 3 times the energy needed to raise the temperature to boiling (shown as the green net heating line).

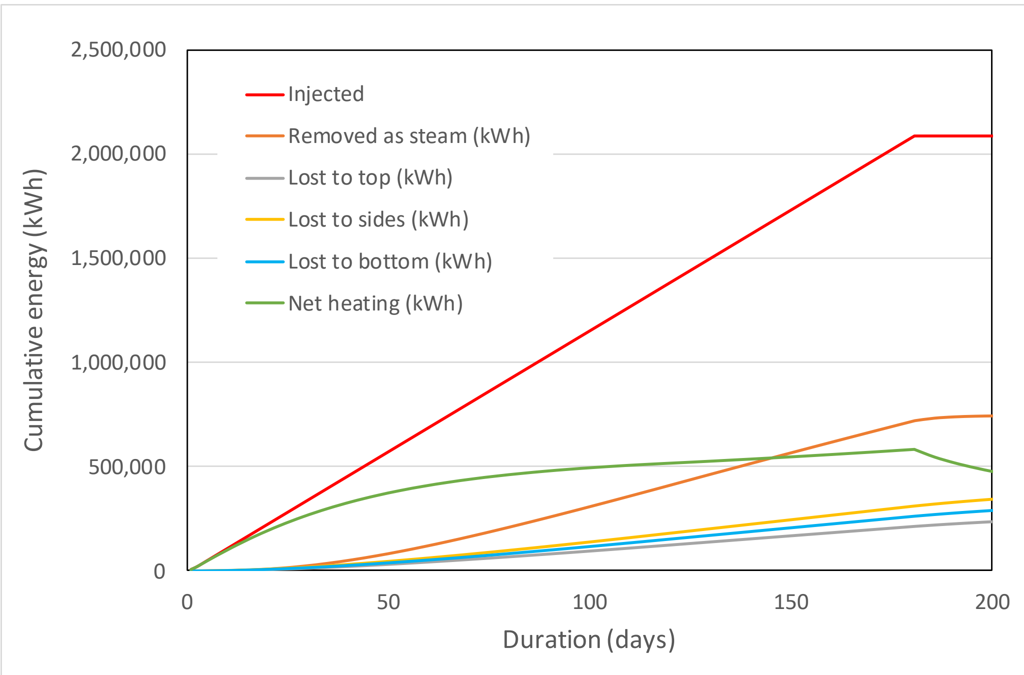

Figure 2. Energy balance for a 30-ft deep site heated to boiling for removal of VOCs. Note the significant amount of energy lost and extracted.

It is important to understand the nature of these heat losses and how they can be minimized.

Heat losses are higher for thin treatment zones

The ratio of surface area to treatment volume is a key parameter for the heat losses, as it governs the area where heat flows away from the target volume. The inverse parameter is the average treatment zone thickness. Figure 3 illustrates energy densities required to raise the temperature and for thermal treatment for an example site.

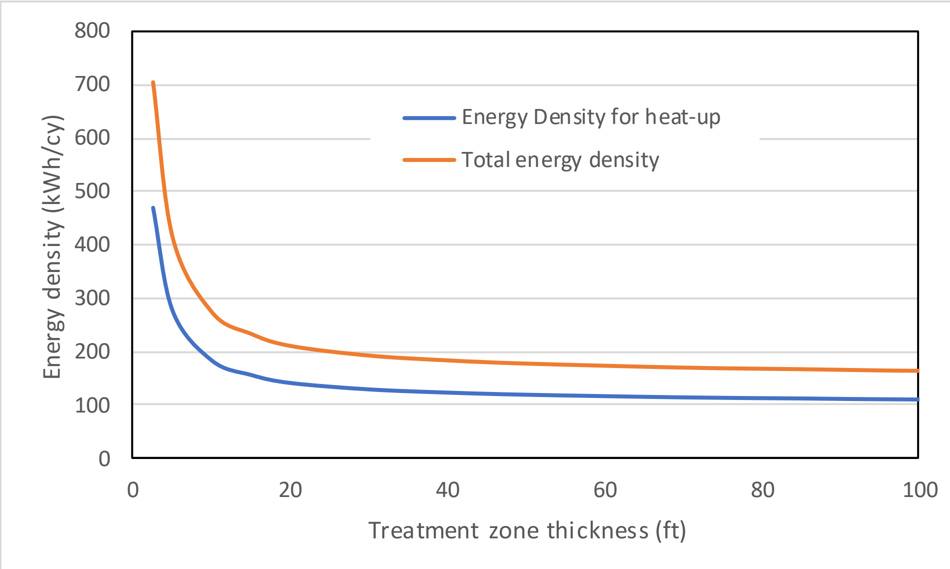

Figure 3. Energy density required as a function of treatment zone thickness/depth. Example case with 99% reduction of PCE in a wet soil with 40% porosity. Heat losses and energy removed by extraction are included.

Note that for sites with a treatment interval of 10 ft or less, the energy densities are high. For sites thicker or deeper than 20 ft the change is modest, as other factors such as surface insulation and groundwater flow become more dominant.

Groundwater flow and liquid extraction moves energy

The impact of groundwater flow into a thermal treatment volume is simulated in Figure 4. These simulations use the same site geometry and power input.

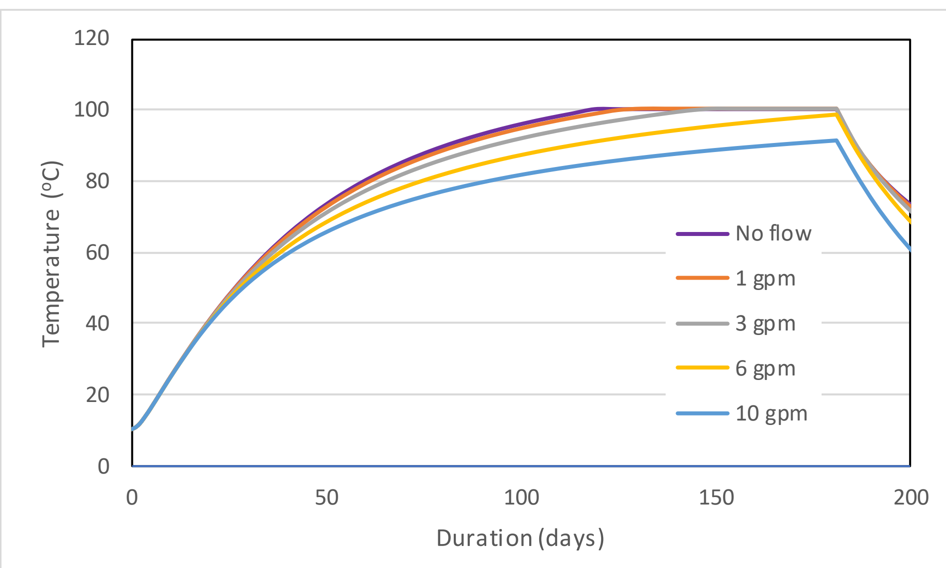

Figure 4. Heating progression at a site influenced by groundwater extraction rate. Example case with 40% porosity and wet soil and a 30 ft deep treatment zone.

Note that in the more extreme cases of 6 and 10 gpm inflow, the site does not reach the target temperature unless a change in heating strategy is implemented. Such changes include the delivery of more power, pumping of water to slow the movement, and injection of steam into the flow zones. These remedies all add to the cost and likely also the duration of the project. It is better to have these factors included in the energy model up front.

Surface heat losses can be significant unless a proper cover is used

The surface cover and insulation properties govern the heat losses to the atmosphere. Figure 5 shows the temperature progressions for a site with the same power input but different R-values. The plot represents the range of no insulation (R1) to a 2-foot thick layer of air-entrained concrete with a thermal conductivity of 0.22 W/mK (R30).

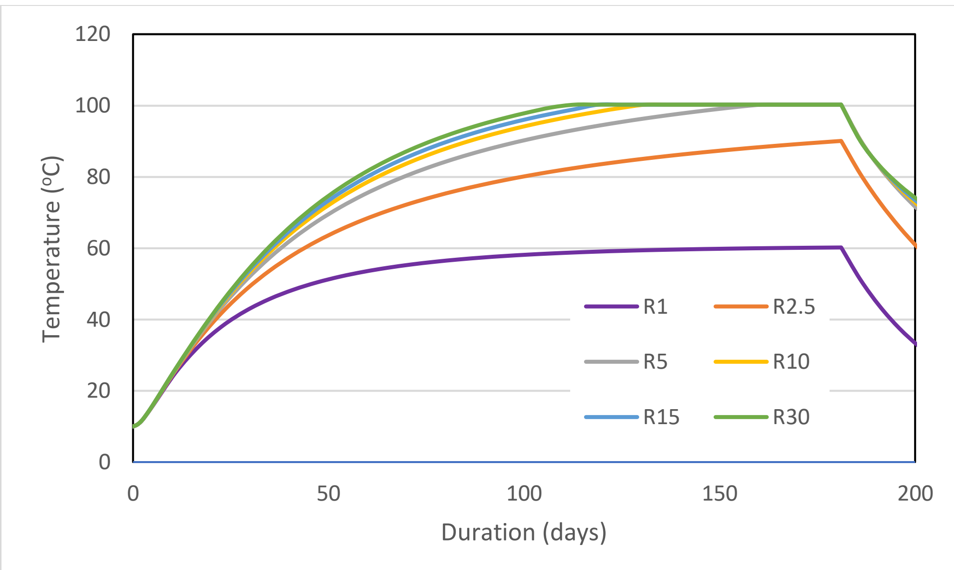

Figure 5. Heating progression at a site with varying insulation values at the surface. Example case with 40% porosity and wet soil and a 30 ft deep treatment zone with the same power input in all cases. R1 represents a simple 1-ft thick concrete or asphalt layer (no insulation).

For this example site, a minimum R-value of 10 is required to achieve boiling after 4 months of heating. Cheap solutions with simple pavement or a thin sprayed layer (R2.5-R5) would lead to either extended operations or the need for a higher power input, resulting in a larger energy bill.

Vapor extraction – pulling too hard can increase energy demand

Dry air moving through the vadose zone can have a cooling effect as pore water evaporating requires energy. By extracting enough vapor to create inward gradients and pneumatic control, but not so much as to facilitate excessive cooling, the energy need can be minimized.

Conclusions – what you need in order to estimate the energy need and duration

To get a reliable estimate of the energy need and duration required to meet project goals, the following parameters are essential:

- Site geometry (surface area, volume, average thickness)
- Groundwater flow and location
- Surface insulation properties
- Energy density needed to vaporize contaminants
- Vapor extraction rates

It is important to incorporate all these parameters into a numerical model such as Heatwave which accounts for how temperature and gradients change over time. Accurate simulation of the heat losses allows for a realistic prediction of both thermal treatment duration, power needed, and energy consumed to meet the goals.