Treat Your Site Right: Power Density Rules

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Abstract

In situ thermal remediation (ISTR) has been implemented at hundreds of sites world-wide, mostly for source zone elimination or reduction. These remedies are aggressive and fast, typically leading to removal of more than 99% of the contaminant mass in less than nine months of operation. Total remedy costs depend largely on the operating time and the amount of energy needed to reach the remedial goals. Therefore, effective power delivery is essential for managing costs. Designing a site with proper power densities is the strongest performance indicator for ISTR systems. Power density is defined as the amount of power applied per unit volume of treated soil, with units usually expressed as watts per cubic yard (W/yd^3) or watts per cubic meter (W/m^3).

Power density values must be high enough to offset site heat losses without negatively impacting the heat transfer mechanism (i.e. soil dry-out or heater failure). This paper presents three case studies of completed electrical resistance heating (ERH) systems, ranging from poor to excellent power densities. The conclusions show the importance of power density in reaching the remedial goals within the project budget and predicted time. Results indicate a successful ISTR system should be designed to achieve a power density of at least 50 W/yd^3 (65 W/m^3). Sites with significant heat loss or water flow may require power densities greater than 100 W/yd^3 (130 W/yd^3).

Power Density

Power density design values should be based on numerical heating models that account for continuous energy removed by the extraction system, energy losses to the surroundings, and a realistic power input. It is also important to consider empirical data from past projects to fine-tune power density models. Power density targets are good indicators of the system's ability to heat up and maintain boiling temperatures within the treatment volume. An ISTR system that heats up quickly will be the most energy efficient because less energy is lost via conduction at the periphery of the treatment volume.

Data analysis from numerous sites indicates a direct relationship between power density and the rate of heat-up (degrees per day). Figure 1 shows the correlation of power density to heat-up rate, illustrating that increased power densities lead to faster heat-up.

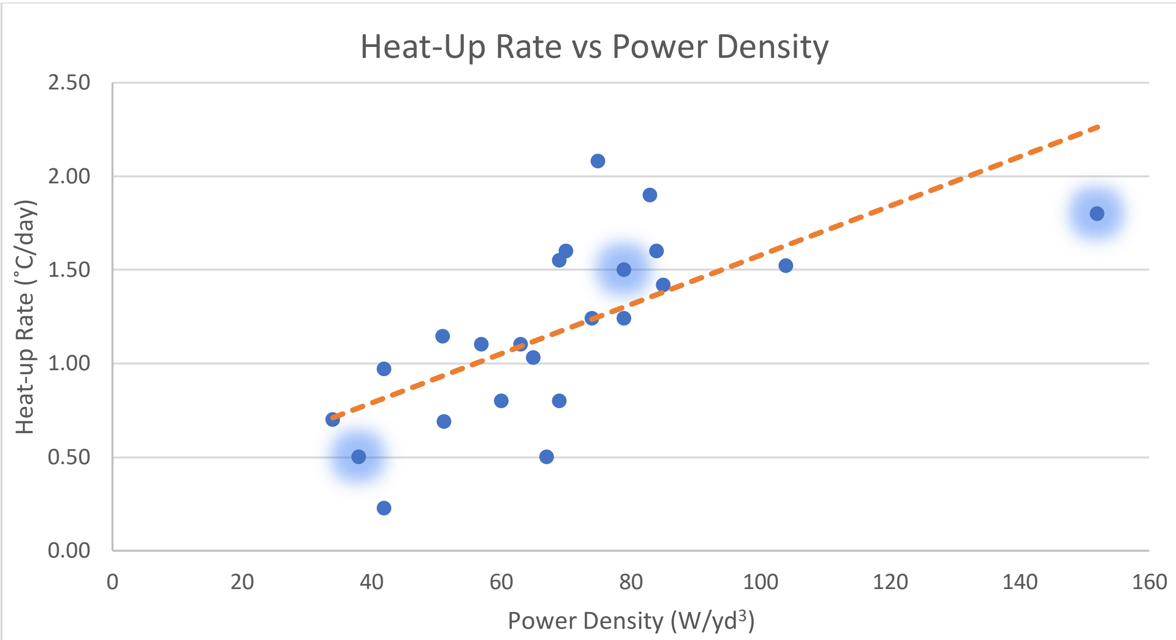

Figure 1. Heat-up rates as a function of power density. Blue highlights represent the case studies discussed later.

Another important relationship occurs between power density and duration of heating. Achieving sufficient power densities will decrease the overall time needed to heat and, therefore, decrease overall project costs. Figure 2 shows this relationship.

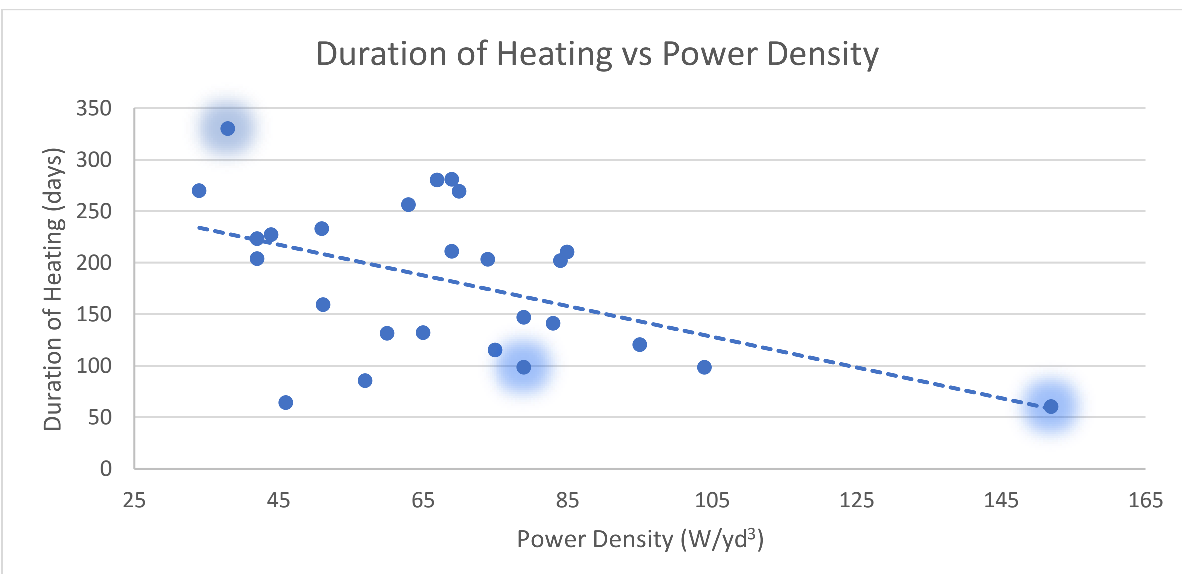

Figure 2. Duration of heating as a function of achieved power density. Blue highlights represent the case studies discussed later.

An ISTR system that is not designed with a sufficient power density may run longer than predicted, increase project costs, and potentially require the installation of additional infrastructure to reach the remedial goals.

Case Studies

Three case studies are presented to show the importance of achieving sufficient power density. Data from each is highlighted in blue on the graphs presented in the above Power Density section.

St. Louis, Missouri

An ERH site in St. Louis, Missouri, had an average power density during operations of 79 W/yd^3 (102 W/m^3) and required 98 days to complete. Figure 3 below shows that consistent power densities in this range equate to a heat-up from 18 °C to boiling in about 64 days. The average heating rate was 1.5 °C per day.

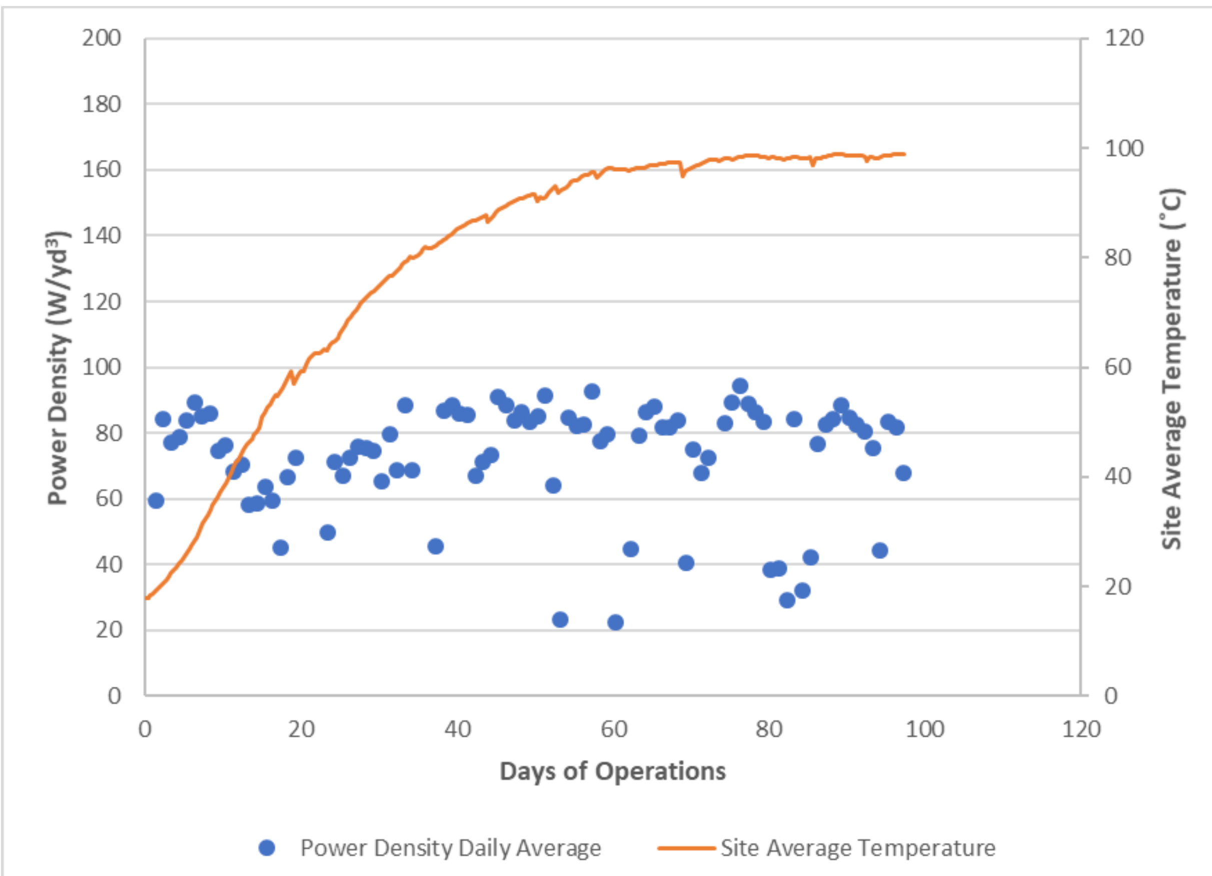

Figure 3. Site average temperature and power density in relation to days of operations

Upstate New York

A site in upstate New York had a power density of 152 W/yd³ (198 W/m³), which is much higher than most projects. A total operating time of less than 60 days was needed to remediate the site. Figure 4 below shows that consistent power densities greater than 100 W/yd³ (130 W/m³) can generate temperature increases from 18 °C to boiling in about 47 days. Heat-up rates averaged 3.2 °C the first two weeks of operations with the overall average at approximately 1.8 °C per day.

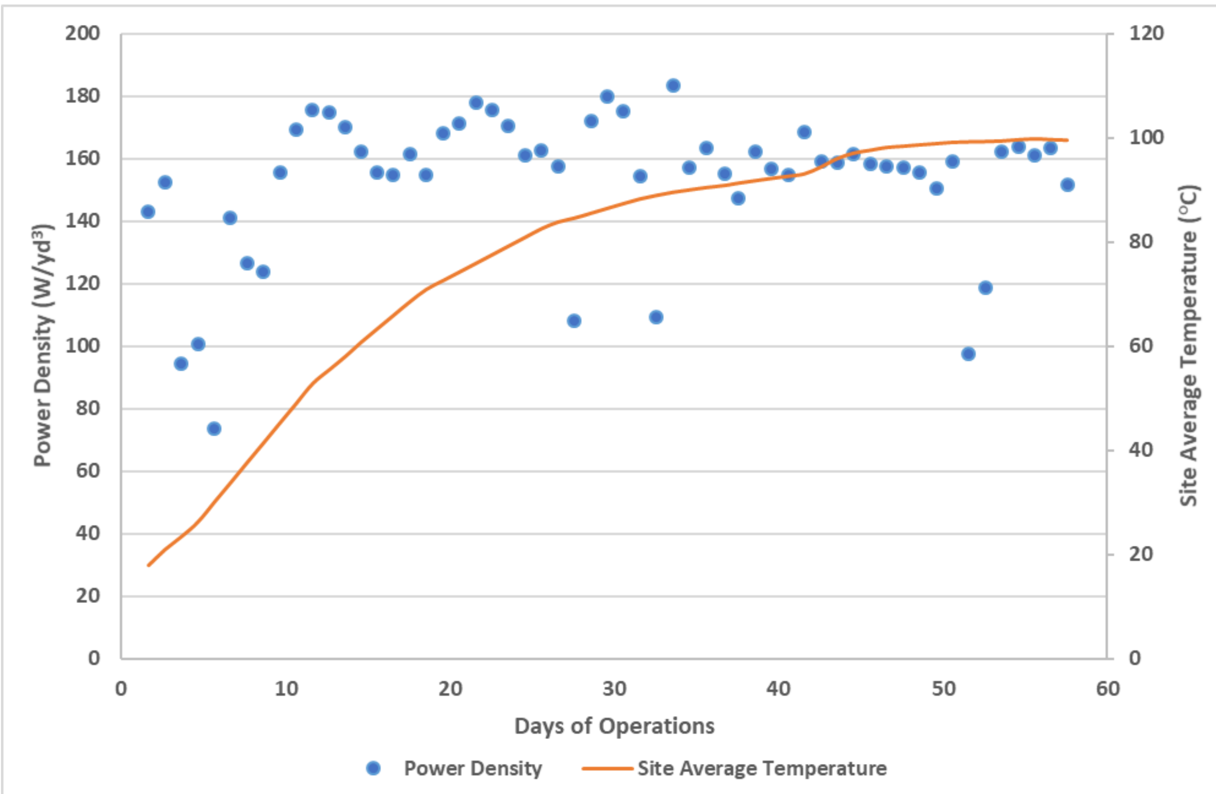

Figure 4. Site average temperature and power density in relation to days of operations

Confidential Project in United States

A confidential project had an average power density of 38 W/yd³ (49 W/m³) and required more than 330 days to complete. Large heat losses resulted in less efficient steam stripping. Figure 5 below shows that temperature increases from 16 °C to boiling took about 152 days. Heat-up rates averaged less than 0.5 °C per day.

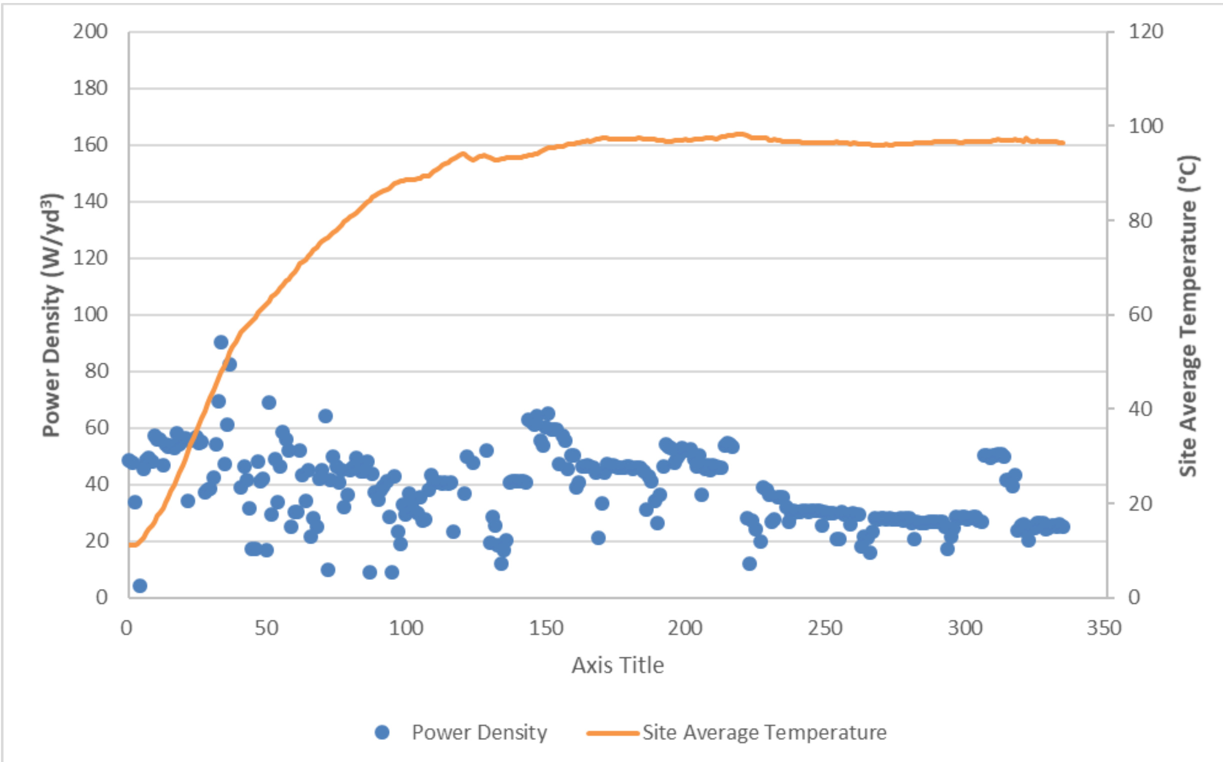

Figure 5. Site average temperature and power density in relation to days of operations

Table 1 below summarizes the three case studies, illustrating the effect power density has on performance.

Performance	St. Louis, MO	Upstate New York	Confidential US Project
Average Power Density (W/yd³)	79	152	38
Heat-up Rate (°C per day)	1.5	1.8	0.5
Days to Complete	98	60	330

Conclusion

Based on numerical heating models and the review of several TRS Group thermal projects, one of the most important design elements for predicting project success, duration, and cost is the designed power density. When reviewing a proposed thermal design, the power density should be at least 50 W/yd³ (65 W/m³).