ARCADIS

Advances in Thermal In Situ Sustainable Remediation (TISR™)

April 18, 2024

TISR is a **sustainable** patented technology (US Pat. Nos. 10,384,246 and 10,688,545) that transfers energy from solar radiation and/or waste heat to the subsurface by means of solar collectors (solar application), modified above grade heat exchangers (waste heat application), a closed loop heat transfer fluid system, and BHEs designed to maximize the conductive heat transfer and target low temperature thermal remediation temperature ranges. The heated fluid is pumped by a small transfer pump through insulated manifolds and subsurface piping to BHEs as shown in Figure 1. Because the system uses solar or waste heat energy, there are **no utility costs incurred for the heating unit**, and only minor power consumption to operate controls and the recirculation pump. In some instances, the minor electrical requirements for system controls and the recirculation pump can be powered by photovoltaic panels and invertors. This enables the system to be completely off the electrical grid and can be used for **remote applications** that are isolated from traditional power sources.

In situ technologies for chlorinated solvents are well-demonstrated; however, sites with complex geological environments and persistent groundwater plumes continue to be a challenge for treatment of chlorinated solvents, limiting the pace of remediation. TISR can overcome these challenges due to its ability to:

- **Overcome the limitations posed by low-permeability and heterogeneous settings**
- **Complement proven and widely-applied remediation technologies**
- **Accelerate the transition from active to passive remediation**

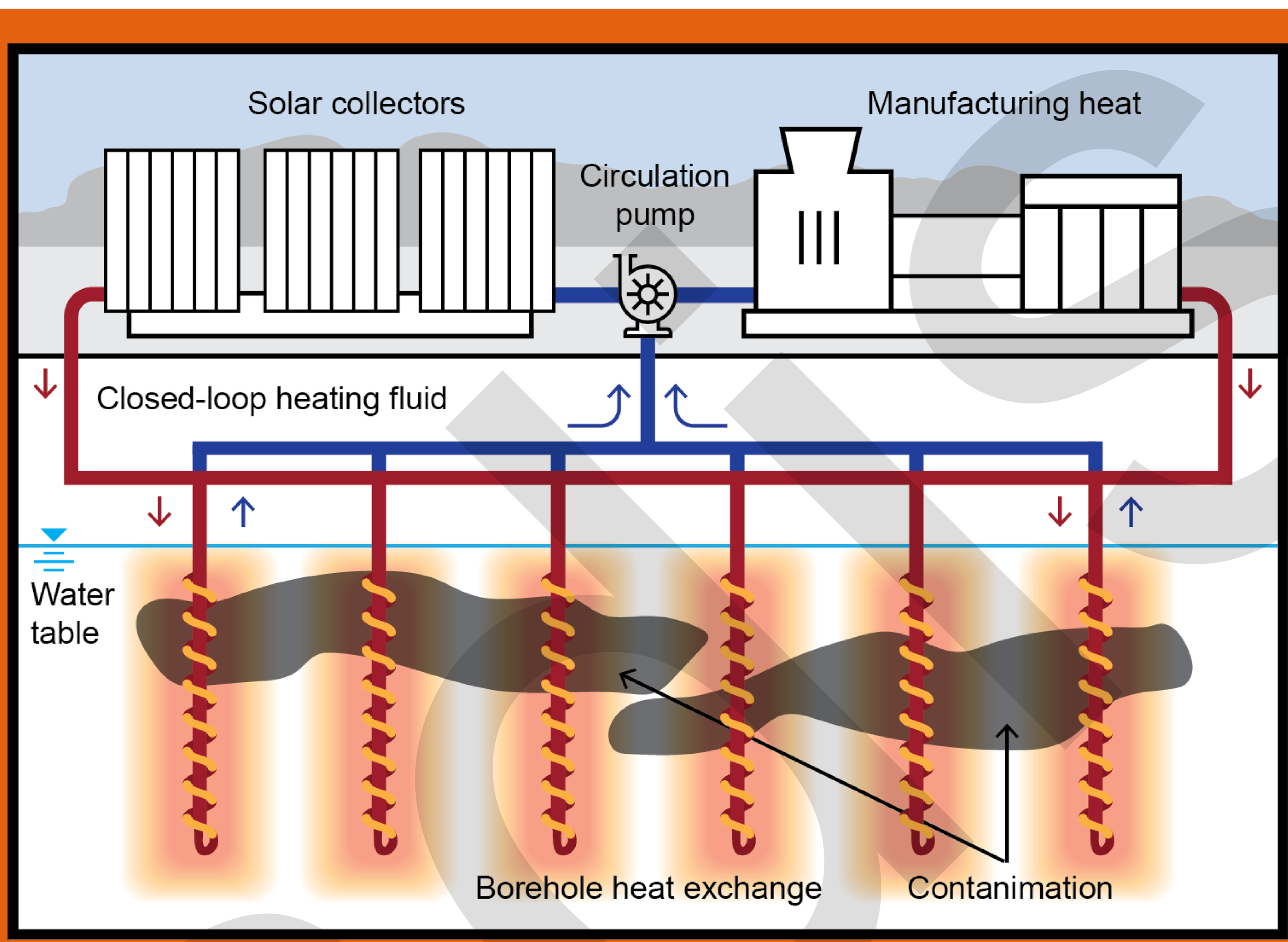

Figure 1: General Process Flow Diagram for TISR (Solar or Waste Heat)

Scan to view our Advances in Remediation Webinar on this subject

Degradation, Chemical Properties and Partitioning, and Heat Transfer

Degradation Processes

The target compound(s) must be evaluated for possible degradation pathways and the system will be designed to optimize that process.

Biotic

- Generally, have an optimal temperature of 15-40°C (enzymes to denature over 70°C)
- Target mesophilic microorganisms

Abiotic

- Hydrolysis is the primary abiotic degradation pathway for chlorinated hydrocarbons
- Ethanes can be targeted by increased temperatures, but ethenes may require biotic

Chemical Properties and Partitioning

Increase Desorption – Compounds transfer from soil pore space
Increased Solubility – Compounds transfer to the dissolved phase
Increase Volatilization – Henry's Law constant increases making compounds more volatile

All of these together makes compounds more readily available for degradation processes and remediation. These changes are monitored during implementation and to date have not created adverse conditions during TISR operation.

Heat Transfer

Heat transfer coefficient between varying soil is only one order of magnitude while hydraulic conductivity for fluid transfer (groundwater recovery or air sparging) can vary 13 orders of magnitude allowing TISR to overcome interbedded low permeability lithologies which can act as a continuing source causing rebound if left untreated.

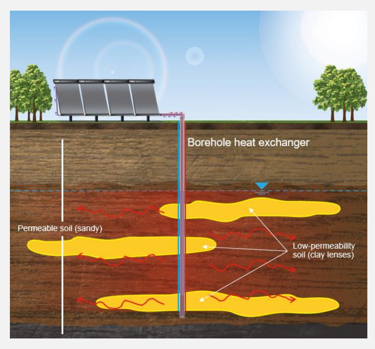

Figure 2: Heat Transfer through Clay

Application

Solar Energy

- Off the shelf solar collectors are utilized to transfer solar energy to heat and transferred to the subsurface
- Over 15 solar energy TISR systems have or are currently operating in 5 countries.
- Collectors have been installed on the ground, trailer mounted, or on roofs (flat or sloped)
- Collectors are easily decommissioned and reusable at other sites following completion of remedial goals
- Designed to account for specific solar insolation with the ability to supplement traditional heating at low solar insolation locations as needed

Denver, Colorado

- TISR pilot test in source area in 2017
- Significant reduction in 1,1-DCE, TCE, and 1,1,1-TCA following TISR commencement
- Vinyl chloride and ethene increases indicate enhanced biotransformation
- 1,1-DCE and TCE transient increase and then decrease suggests enhancement of other processes

Figure 3: Solar Collector Installation

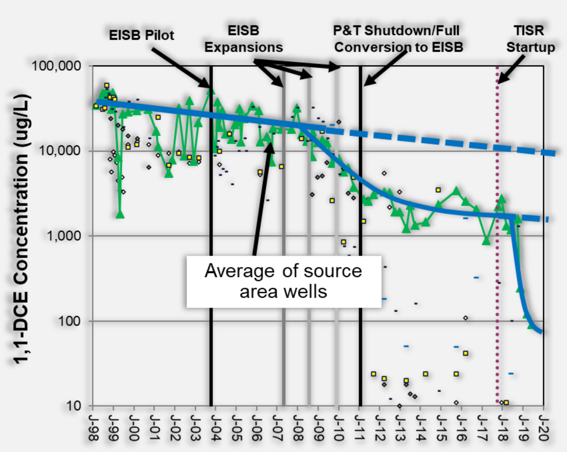

Figure 4: Denver, CO Solar TISR and EISB Injections Results

Waste Heat

- Waste heat has been utilized from remediation equipment as well as client facility operations
- Waste heat can supplement solar energy or can be supplemented with traditional heating but provide a sustainable costs savings
- Allows for continuous heating
- Can be integrated into existing production or processing facility with no impact to operations

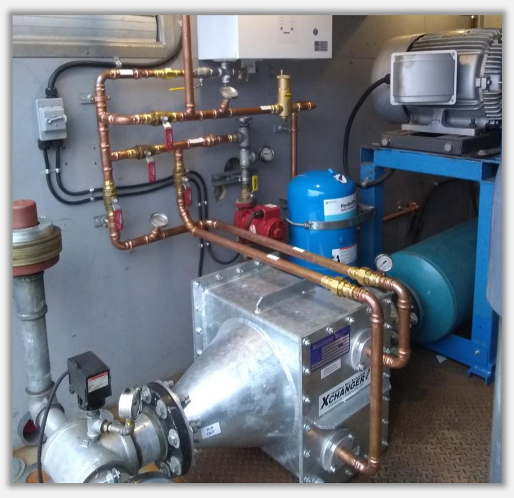

Figure 5: Waste Heat Capture from an Air Sparge System

Syracuse, New York

- Waste steam utilized from active facility and heat is transferred to the subsurface through the closed loop TISR system
- No downtime for facility
- Started in March 2022 with significant heating over the short period of operation (20+°F increase 10 ft from BHE)
- Set to reach target temperature at 6 feet from the BHEs ahead of goal

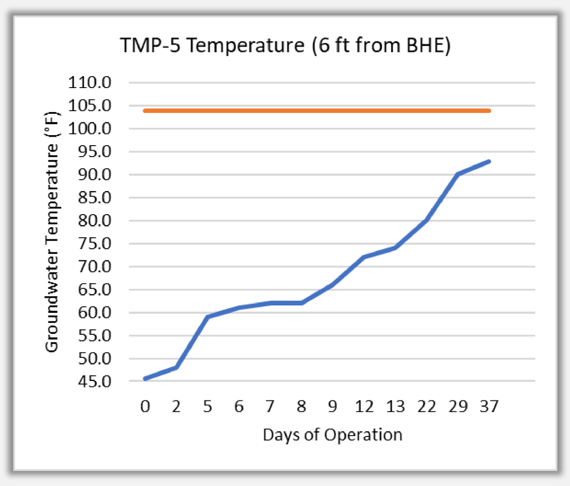

Figure 6: Groundwater Temperature Increases from Steam Waste Heat System

Complimentary Technologies

TISR can be utilized symbiotically with other remedial technologies:

- Air sparging
- Biosparging
- NAPL extraction
- Enhanced reductive dechlorination injections
- Chemical oxidation injections

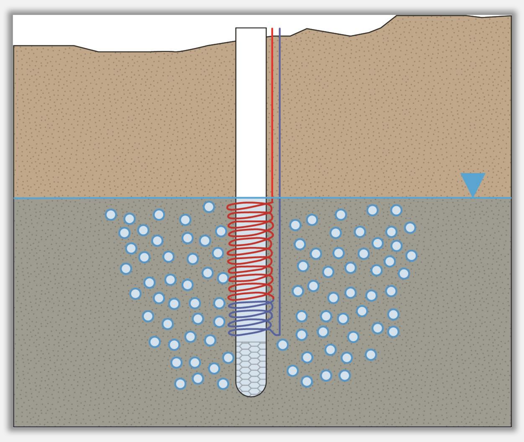

Figure 7: Symbiotic Utilization of TISR and Air Sparging

Air Sparge and TISR

- Heating increases desorption, dissolution, and volatilization to enhance effectiveness of contaminant stripping
- Sparging increases dissolved oxygen to enhance aerobic degradation
- Increased volatility may allow for remediation of semi-volatile contaminants via air sparging
- Capital cost of TISR equipment and installation approximately 10-15% increase over air sparge alone but reduction in operating duration and associated expenses will result in a positive return on investment

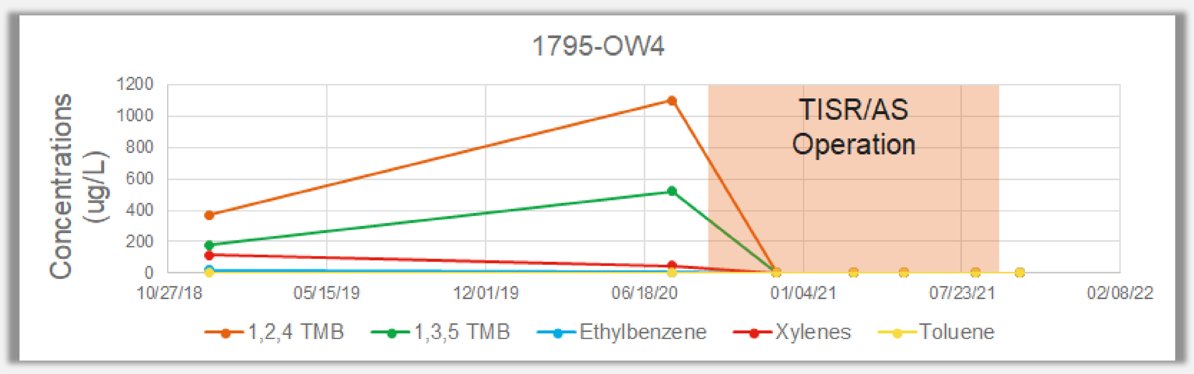

Figure 8: Upstate New York Waste Heat TISR/AS System Results