Challenges Encountered on Heavily Contaminated Thermal NAPL Sites

TERRATHERM
a Cascade Company

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SAME DCHWS
Design and Construction Issues at Hazardous Waste Sites

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Why Focus on NAPL Recovery?

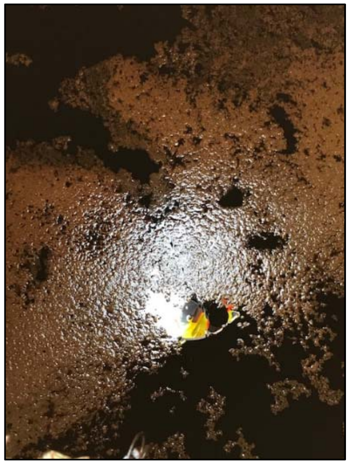
- At chlorinated sites ~98% of mass typically is removed in the vapor phase. Limited focus needed on NAPL recovery.
- For some chemical mixtures, NAPL recovery is dominant. Thermal design needs to consider it.

- Geology and hydrogeology typically determine technology selection. Chemical mix determine how the mass comes out,- nearly independent of heating technology.
- Extraction strategy is critical, if NAPL recovery is expected.
- Increased focus on sites where NAPL recovery is dominant, as the “easy” sites are remediated and more complex sites remain.

Governing Mechanisms

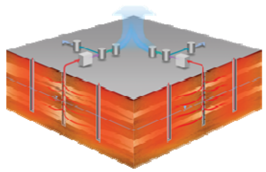
- **Viscosity:** reduced by heating, which increases the mobility of the NAPL and therefore the ability to pump it. The higher the initial viscosity, the greater the reduction.

- **Steam Displacement/Pushing:** injection and/or generation of steam in the subsurface displaces NAPL and physically pushes it towards extraction wells.

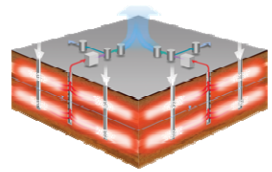


In Situ Thermal Technologies

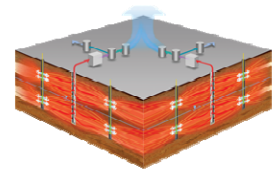
Thermal Conduction Heating (TCH / ISTD)



Steam Enhanced Extraction (SEE)

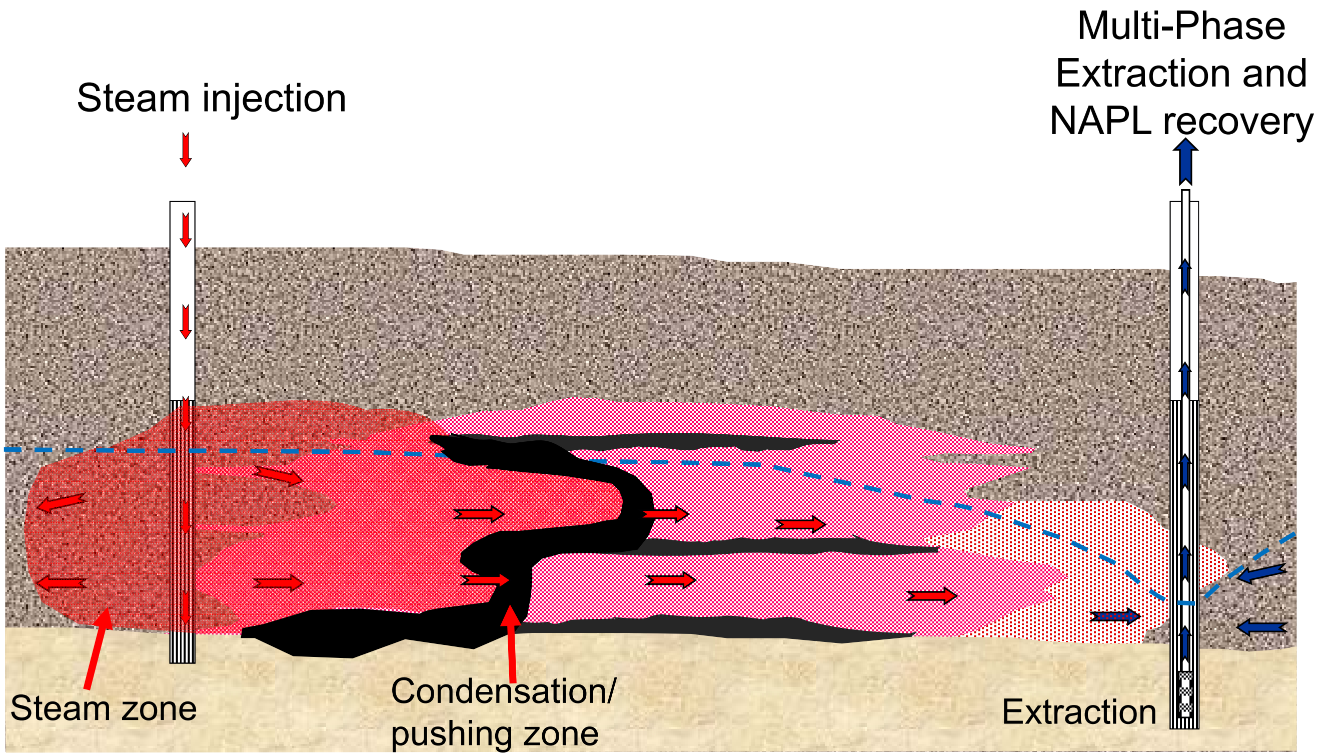


Electrical Resistance Heating (ERH)

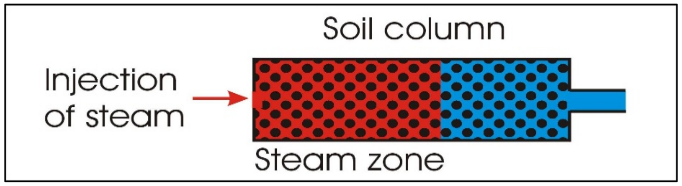


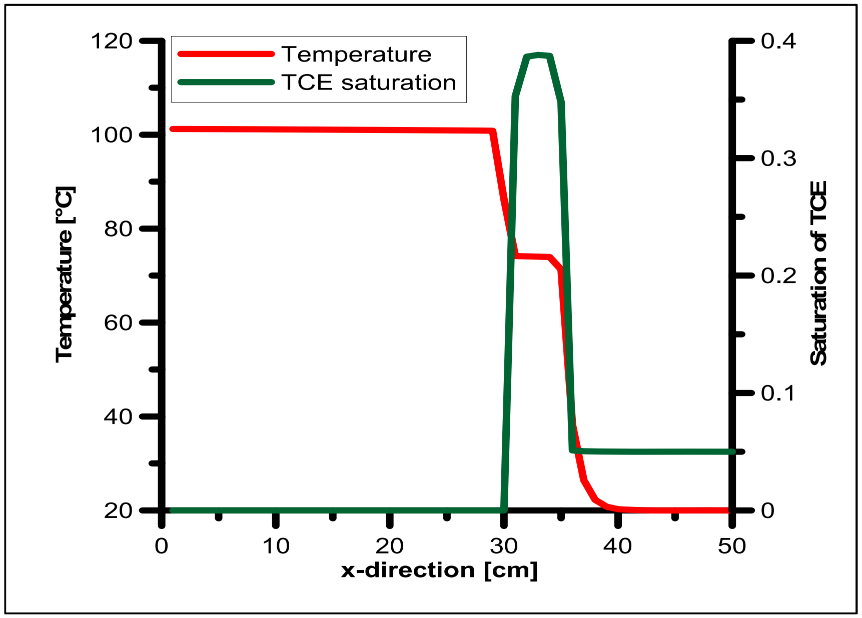
SEE preferred at NAPL sites when possible, due to added benefit of steam flushing/displacement

Physical NAPL Mobilization



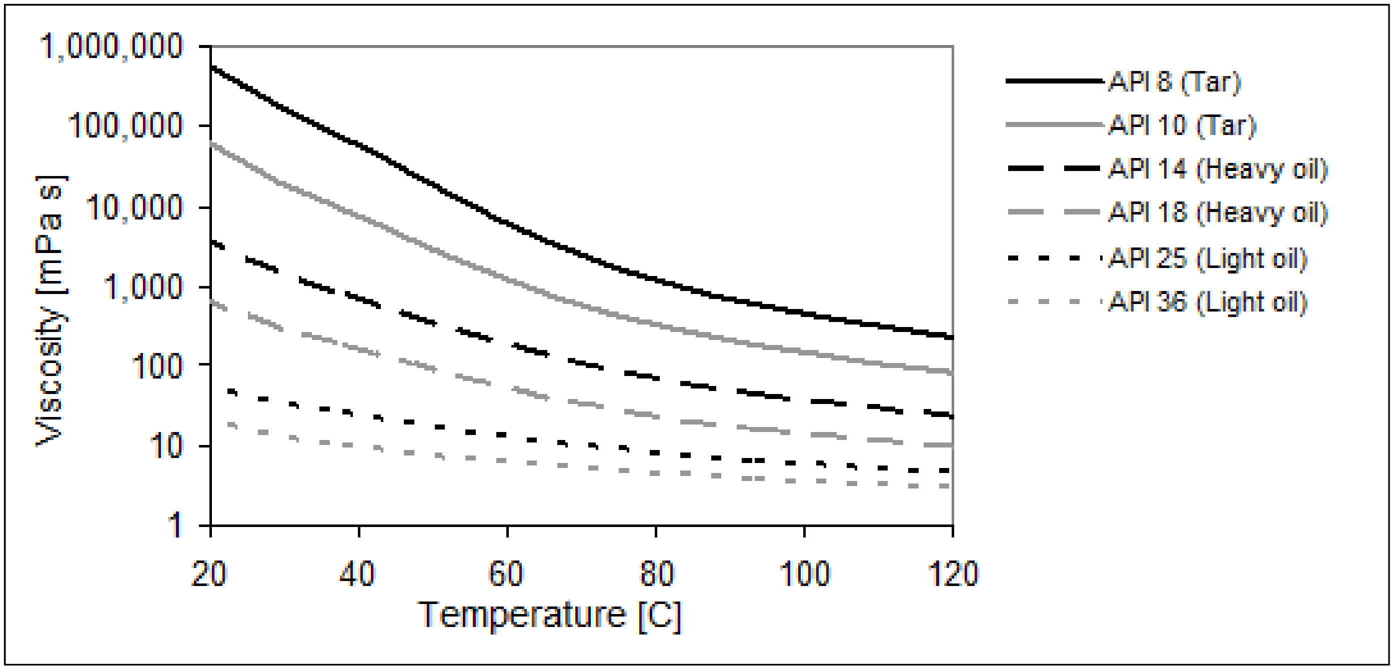
Steam Injection in Unsaturated TCE Sand



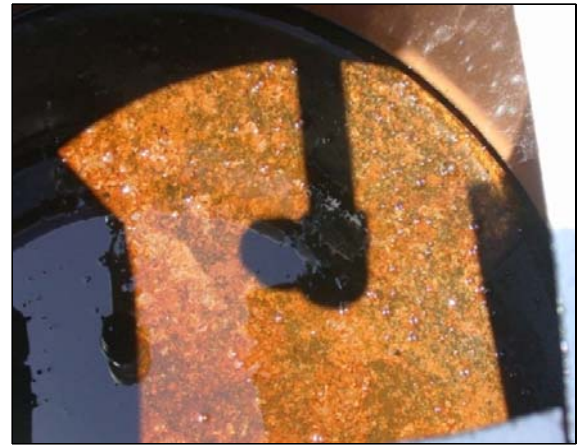


Courtesy of Jacob Gudbjerg, Danish Technical University

Viscosity Reduction

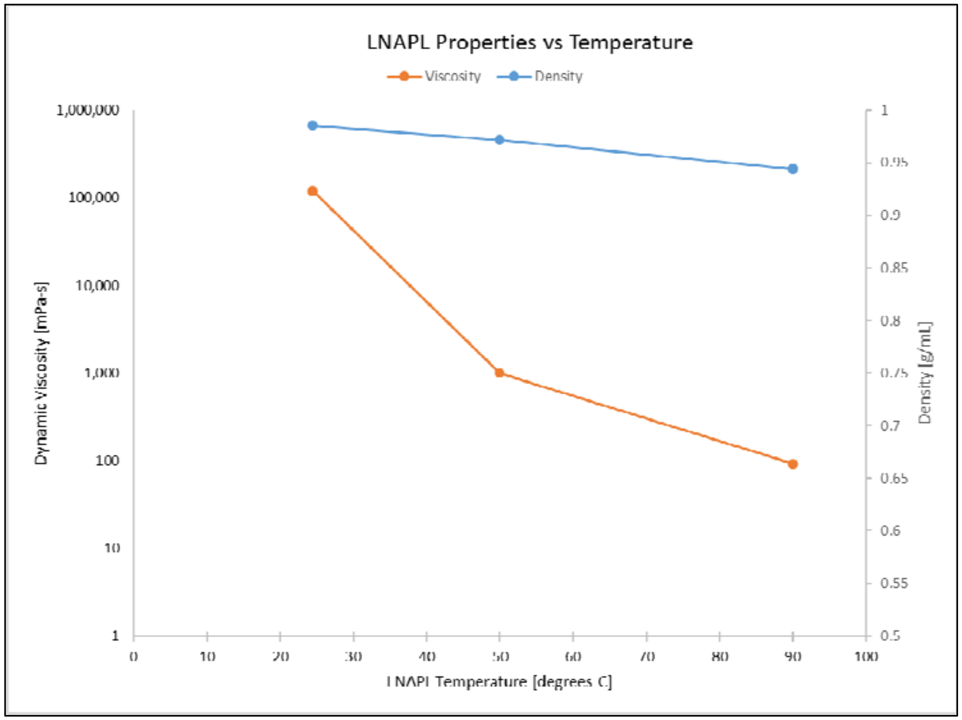


- 1,000-3,000 times for tar
- 10 times for light oils



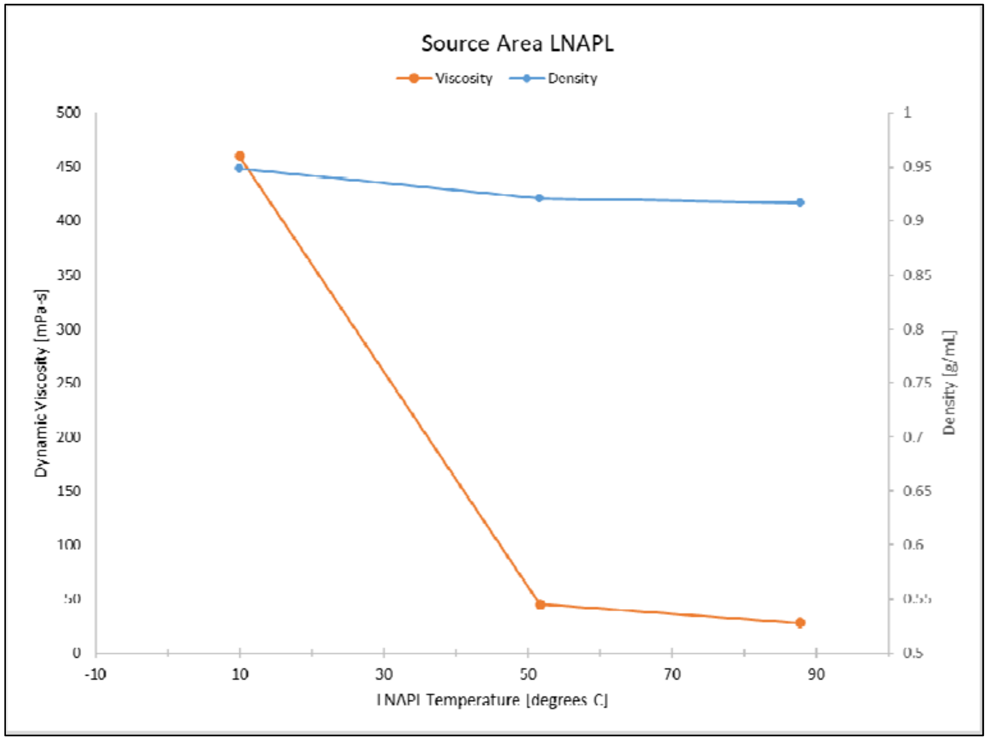
TS Study – No 6 Fuel Oil

- Viscosity and Density were measured at ambient (~24 ºC), 50 ºC and 90 ºC via ASTM D445 and ASTM D1481, respectively.
- Viscosity diminished from 120,000 mPa·s to 93 mPa·s, 3 orders of magnitude!



TS Study – Hecla Oil and Phthalates (Source)

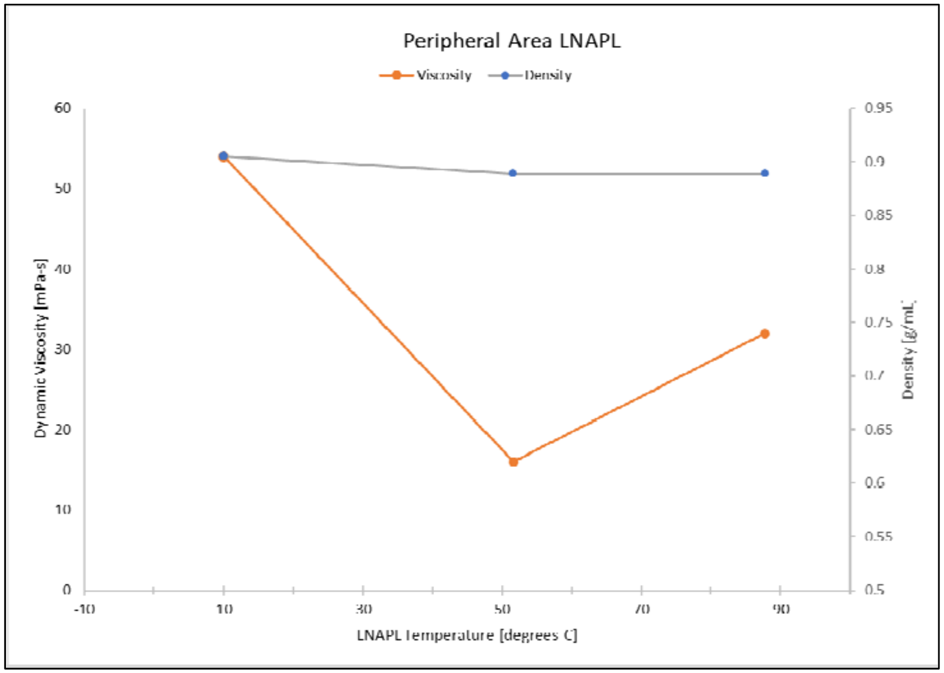
- Viscosity and Density were measured at ambient (10 ºC), 52 ºC and 88 ºC via ASTM D445 and D1481, respectively
- Viscosity diminished from 460 mPa·s to 28 mPa·s, ~1 order of magnitude



TS Study – Hecla Oil and Phthalates (Peripheral)

- Hecla oil with Di-n-octyl phthalate (DOP)
- Viscosity and Density were measured at ambient (10 ºC), 52 ºC and 88 ºC via ASTM D445 and D1481, respectively

Viscosity increased again with temperature



TS Study – Hecla Oil and Phthalates (Peripheral)

- Pure Di-n-octyl phthalate (DOP) shows continued decrease viscosity decrease with temperature
- For plastisol systems (polyvinyl chloride particles suspended in plasticizer), viscosity increase with temperature after approximately 54 C.

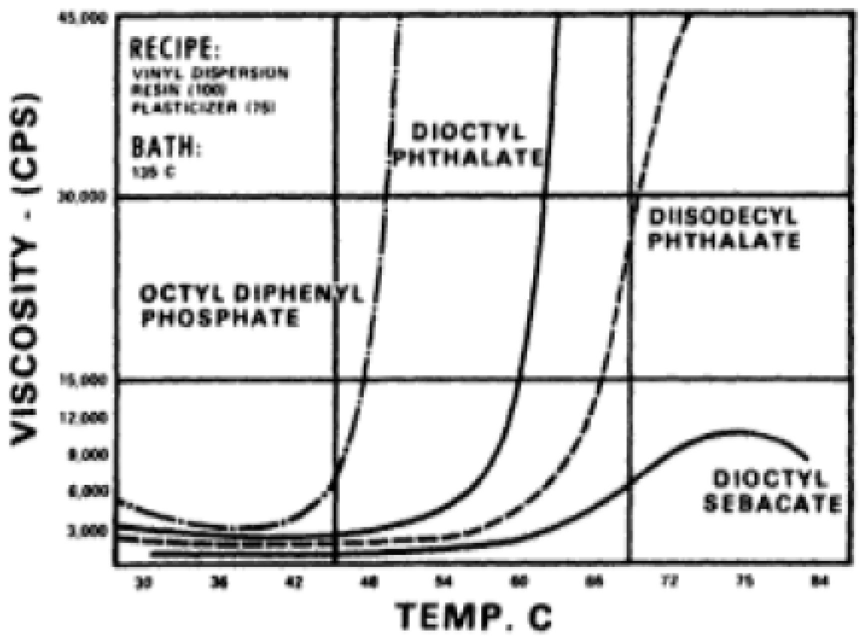
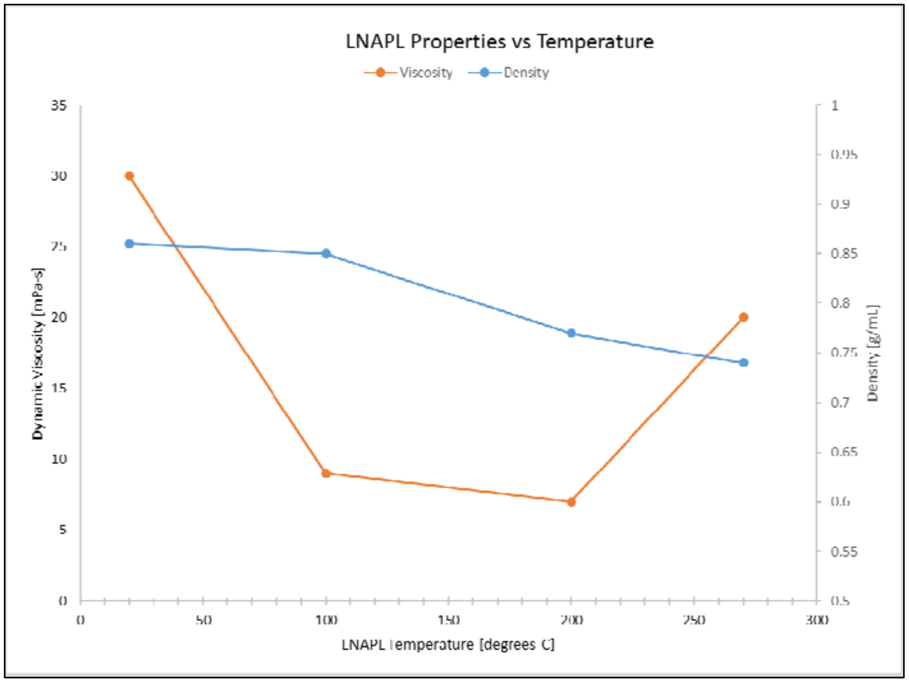


Figure from Berins, Michael L. SPI Plastics Engineering Handbook of the Society of the Plastics Industry, Inc. 1991, Springer US. DOI 10.1007/978-1-4615-7604-4.

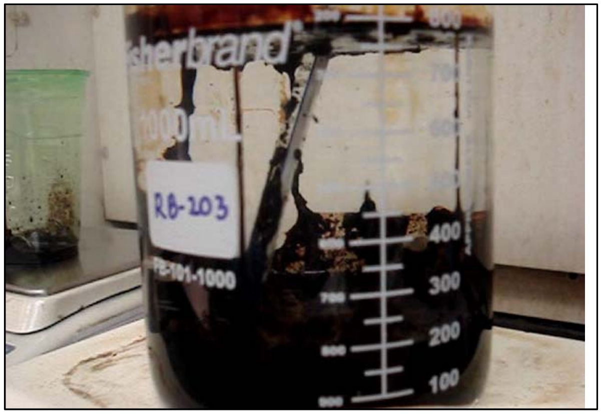
TS Study – MGP LNAPL

- Viscosity and Density were measured at ambient (~20 ºC), 100 ºC and 200 ºC and 270 ºC via ASTM D445 and ASTM D1481, respectively.
- Viscosity diminished from 30 mPa·s to 7 mPa·s up to 200 ºC. Increase in viscosity beyond 200 ºC due to stripping off of lighter-end VOCs.



MGP NAPL Behavior

MGP DNAPL at 50-70ºC (Movie)



- Water about 40ºC
- NAPL between 50 and 70ºC
- Boiling DNAPL to LNAPL Conversion – Convective Action

MGP DNAPL100ºC (Movie)

- Water is about 80-90ºC (below boiling point)
- Conversion of DNAPL to LNAPL and LNAPL to DNAPL

75ºC Viscosity (Movie)

- Depending on physio-chemical properties DNAPL viscosity can be reduced substantially, increasing pumpability and overall extraction

NAPL Mobility in Wellfield

- NAPL may be very viscous when collected at wellhead
- Viscosity increases again when cooled down
- Remaining NAPL is immobile

NAPL right after collection

Now the NAPL is Mobilized – What Then?

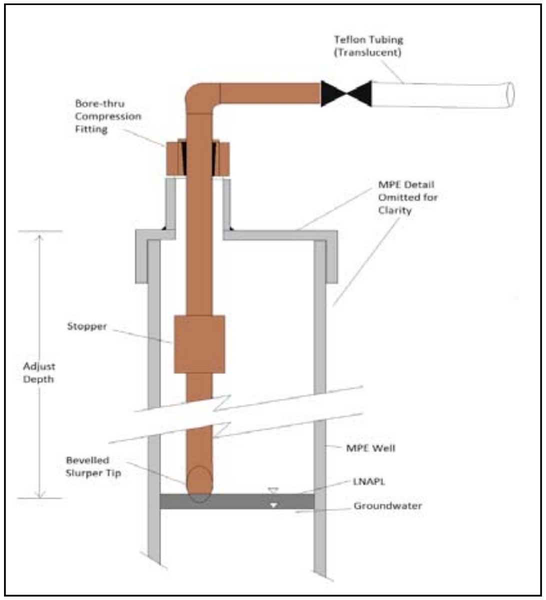
Pumps

- Traditional pumps
    - Pneumatic preferred
    - Issues capturing fluctuating NAPL
    - May “gum up”
    - High maintenance
- Piston type pumps
    - High temp version required (250 F)
    - Easier to maintain from surface
    - Issues capturing fluctuating NAPL
    - Expensive
- Slurping

High temp Black Hawk operating at SEE site

MGP waste on downhole pump

Slurping – LNAPL Removal



Slurper boring

Well with both slurping and pneumatic pumps installed

High vacuum slurper system

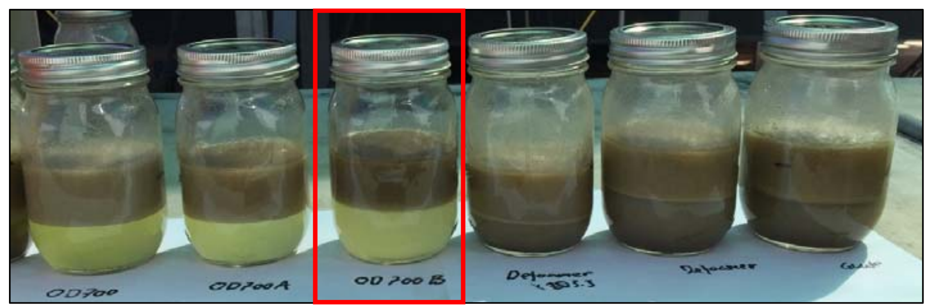
Process System – Emulsions and Bio

LNAPL

Cloudy matter (dead bacteria and minerals?)

Water

Emulsions in weir tank

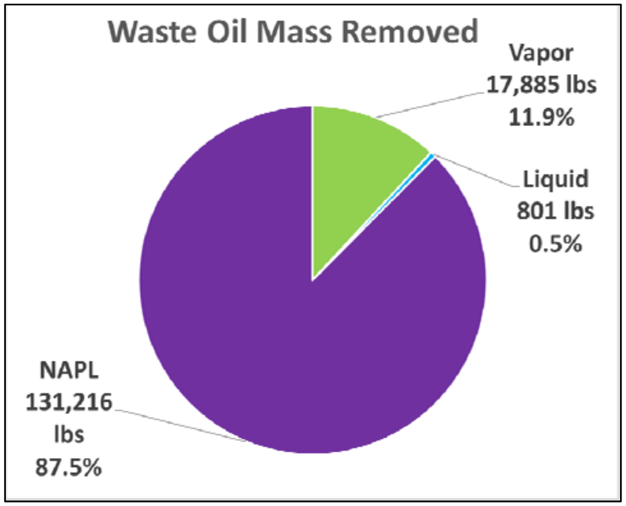


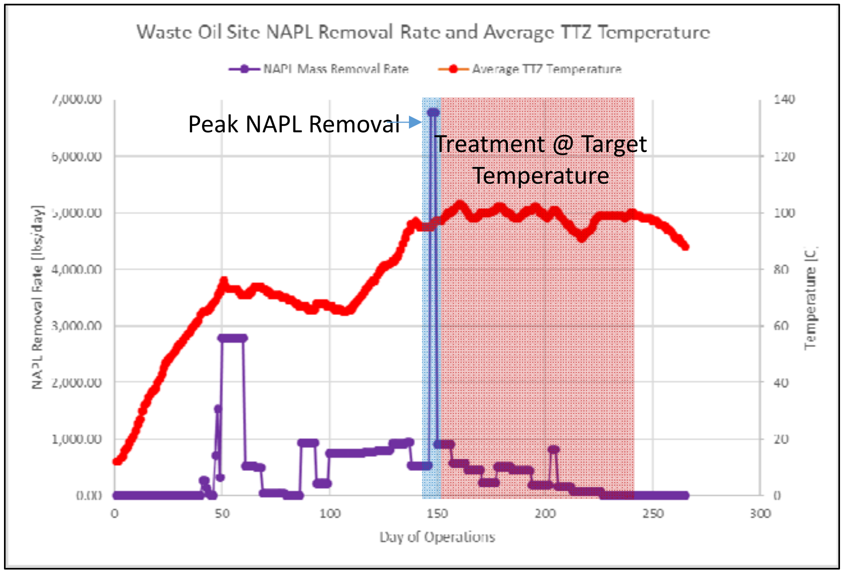
Process System - Considerations

- Separation
- Keep it hot to storage tank?
- Storage
- Disposal
- Maintenance

Enough material for a separate presentation!

Case Study – Waste Oil Site





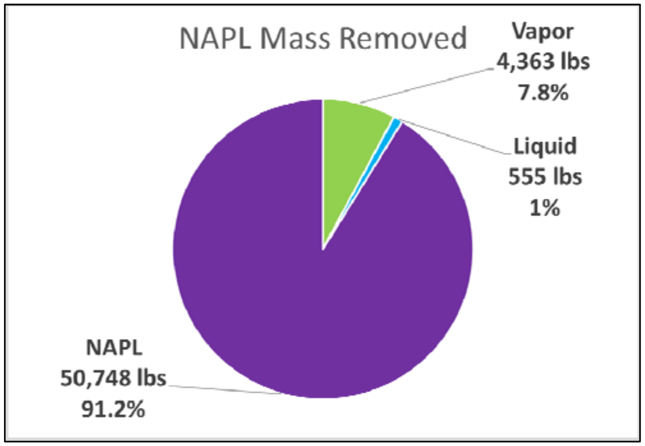
Thermal Technology: SEE

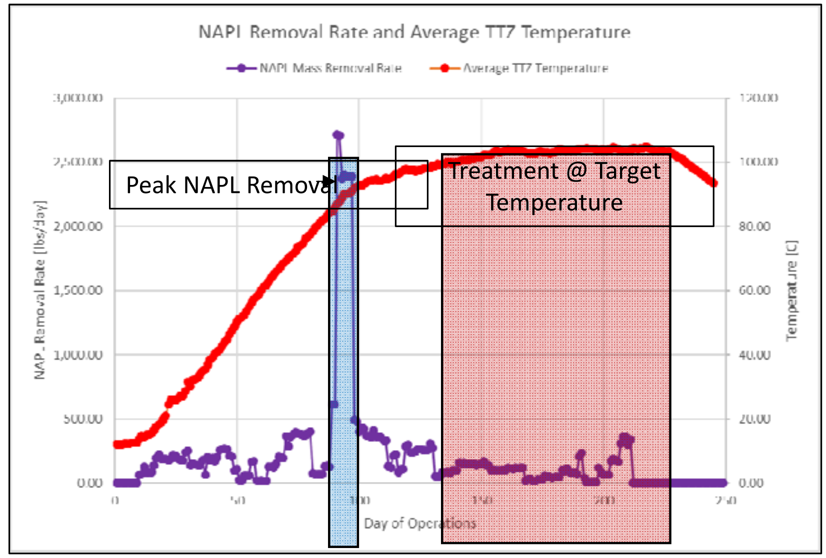
Contaminants: Pooled and residual LNAPL consisting of a variety of oil types including: motor oil, lubricating oil, diesel and kerosene

Total Mass Removed = 149,903 lbs in 265 days

NAPL Mass Removed = 131,216 lbs, 87.5% of total

Case Study – NAPL Site





NAPL removal rate was difficult to measure and is therefore associated with some uncertainty.

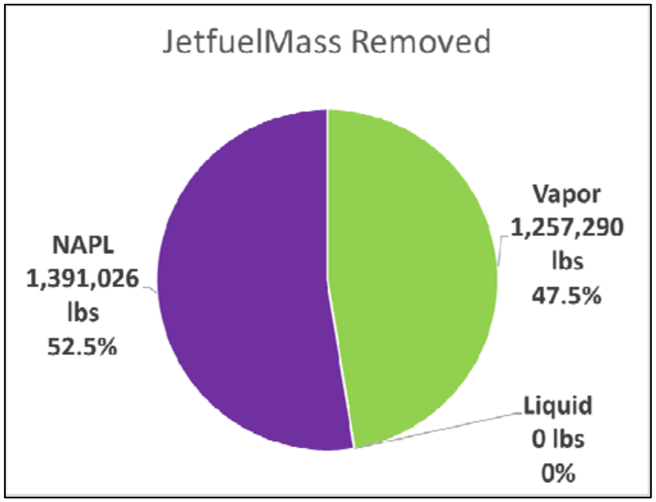
Thermal Technology: TCH

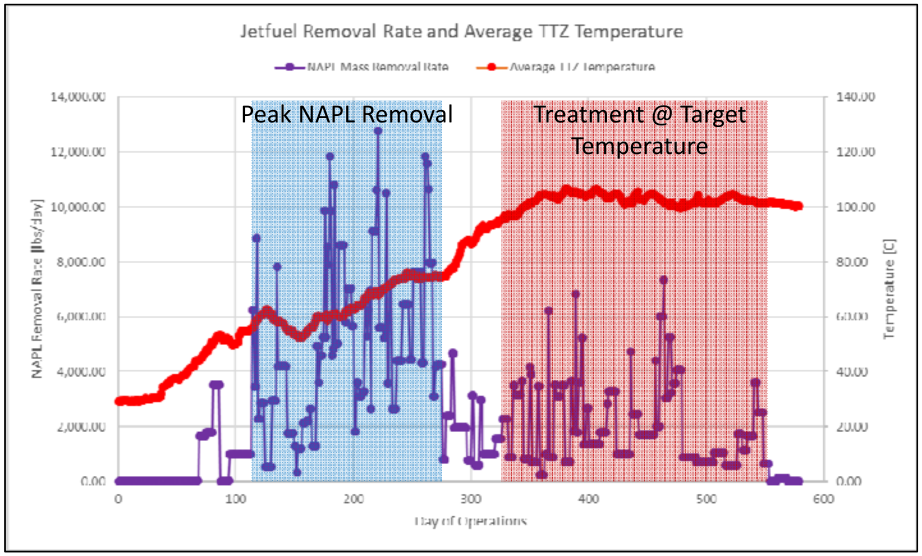
Contaminants: DNAPL pooled on tight clay till interface originating from DDT, TCA and DBCP chemical manufacturing

Total Mass Removed = 55,666 lbs in 249 days

NAPL Mass Removed = 50,748 lbs, 91.2% of Total

Case Study – Jet Fuel Site





Thermal Technology: SEE

Contaminants: Jet Fuel

Total Mass Removed = 2.6MM lbs in 579 days

NAPL Mass Removed = 1.4MM lbs, 52.5% of Total

Conclusions

- At some thermal sites NAPL removal is the dominant mass removal mechanism. Important to identify upfront.
- Viscosity change hard to accurately predict. Tests often a good idea.
- Not all NAPL may come out, but remaining mass is typically immobile.
- Design has to carefully consider how NAPL mass is captured and treated.