

A Laboratory Test to Evaluate Potential for Steam Enhanced Removal of Coal Tar in a Sand Matrix

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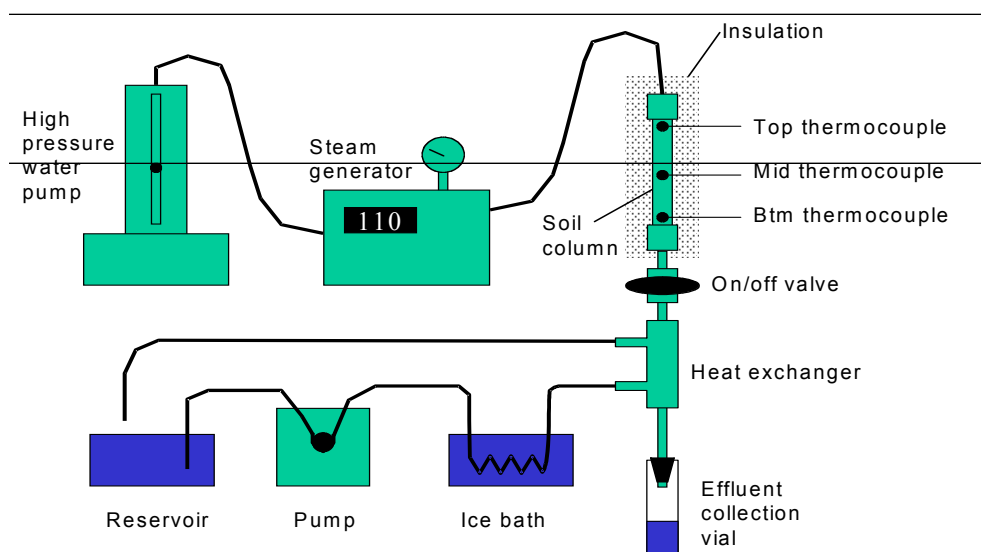
Objective

This laboratory scale treatability study was conducted to determine if coal tar constituents of concern might be removed from sandy soils by passing steam through a sand/coal tar matrix, and to assess the hydrocarbon recovery that might be observed under field conditions. These experiments were not run to determine an ultimate percentage of tar mass, nor individual constituents that could be removed by steam. That number is a function of the vapor pressures of the less volatile fractions of the tar mix, the initial concentration of the tar in the soil, the percentage of the NAPL that is mobilized by hot water and steam, the mass of steam passing through the column, and the position of the hydrocarbon liquid within the sand-pack. The experiment presented herein is to document what can be removed from sand containing high amount of coal tar using a modest amount of steam. Data are sought to describe the steam distillation properties of the sample coal tar.

Procedure

In this experiment, 575.3 gm of medium-grain size sand, moistened with an additional 10 ml of water, was thoroughly mixed with 38.2 gm of chilled tar liquid, taken from a former manufactured gas plant in Charleston, South Carolina. These proportions are representative of an overall tar concentration of 66,400 mg/kg on a dry soil basis. The sand/coal tar mix was packed into an 8" long, 2" ID stainless steel column with a packed soil volume of approximately 341 ml. The sand was lightly tamped during packing to avoid gas pockets. The porosity is calculated to be 0.363 assuming a sand grain density of 2,650 kg/m³, giving a 124 ml column pore volume. The column was placed vertically in a holding clamp. Thermocouples were attached at several locations on the column (Figure 1).

Figure 1. Laboratory setup for Steam Enhanced Extraction Study.



The column and the steam line were wrapped with heater tapes and carefully insulated. The heater tapes were energized by application of a variable ac voltage, controlled by rheostats. The input voltages were calculated from the measured sand pack temperatures such that the heat input to the tapes equal to the heat loss from the core at the experimental temperatures.

Effluent liquids were condensed using a water-cooled heat exchanger. Effluent condensate was collected directly in 40 ml VOA vials submerged in an ice bath to minimize losses of volatiles. Altogether 11 aliquot samples were collected during the course of this test.

Pressure was cycled after the sand pack column had reached steam temperature at the target pressure of 6 psig. Pressure cycling has been shown to be more representative of thermodynamic equilibrium than for constant pressure flow where channeling would lead to mass transfer limitations. Pressures were cycled by closing the effluent valve for a period of time (approximately 3 minutes for each cycle), until the pressure in the entire column had increased about 4 psig. When the valve was opened, liquid effluents were collected, and the pressure in the bottom of the column (effluent end) dropped to 6 psig. This release period lasted about 3 minutes, typically producing about 11 ml of condensate, equal to about 0.1 pore volumes. When sample vial was filled, the exit valve was closed, the vial changed, and another cycle was initiated.

During the 134 minutes of steam injection, about 341 g of steam were injected, and 336 g of condensate were collected, equivalent to approximately 2.63 sand pack pore volumes as steam condensate. One coal tar sample, and 11 effluent condensate samples were collected and analyzed for Monocyclic Aromatic Hydrocarbons (MAHs), and Polycyclic Aromatic Hydrocarbons (PAHs) using MSE/GC/FID (EPA 3570 and EPA 8100mod.).

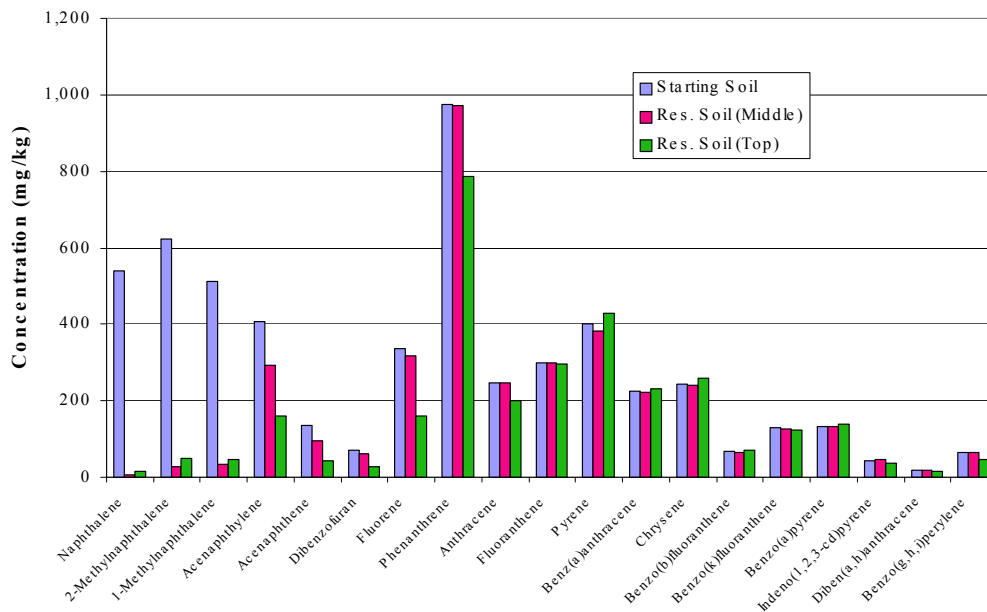
After 134 minutes of injection, the steam generator was shut down, the column was sealed at one end and cooled for one hour in ice water. Then the column was opened, and 3 discrete samples representing the top, middle and bottom were collected. The four soil samples (starting soil, and post-steamed samples collected from top, middle and bottom) were also analyzed for Monocyclic Aromatic Hydrocarbons (MAHs), and Polycyclic Aromatic Hydrocarbons (PAHs) using MSE/GC/FID (EPA 3570 and EPA 8100mod.).

Results and Discussion

After about 18 minutes of steam injection at a rate of 153 gm/hr, the first sample tube was nearly filled with about 1 ml of NAPL and 34 ml of water. After an additional 11 minutes, a second sample tube was filled with a similar fraction of NAPL. The next 8 samples showed decreasing fractions of oil to water in the condensate (of the order of 1/3 ml in a 35 ml liquid sample).

Nineteen different PAHs were identified and quantified in soils analyzed after completion of the test (Figure 2).

Figure 2: Scaled Soil PAH Concentrations



Several features of the data set are significant. First, the concentrations of most components identified were higher in the bottom sample than in the starting soil. This indicates some downward NAPL mobility and some sample concentration bias. The bias is clear from the relative concentrations of low volatility compounds such as anthracene, benz(a)anthracene, and benzo(a)pyrene that were not significantly affected by the steam flow. The same pattern of relative concentrations is seen for such compounds when comparing the starting soil concentrations and the three residual soil sample concentrations. But the data for the bottom sample also show that the bottom sample retained the volatile fractions. This is presumed to be due to heat losses from the column bottom that inhibited vaporization processes at that location.

Figure 3-5 show the measured concentrations of more volatile PAHs, and highly volatile MAHs as a function of efficient pore volumes. Concentrations of naphthalene, 2-methylnaphthalene, and 1-methylnaphthalene in the effluent liquid decrease significantly as a function of increasing number of pore volumes of effluent produced while the concentrations of acenaphththylene, acenaphthene, dibenzofuran, fluorene, phenanthrene, anthracene, and pyrene remain relatively constant and low. Other work has shown that the concentrations of the low volatility components in the effluent stream will remain low until sufficient mass of more volatile compounds is removed to allow for a significant increase in the mole fraction of the less volatile compounds. Thus, with time, most of the compounds identified could be vaporized. But the energy costs will be problematic if the goal is to vaporize all PAHs from soils including the high immobile hydrocarbon compounds.

Figure 3: Concentrations of More Volatile PAHs

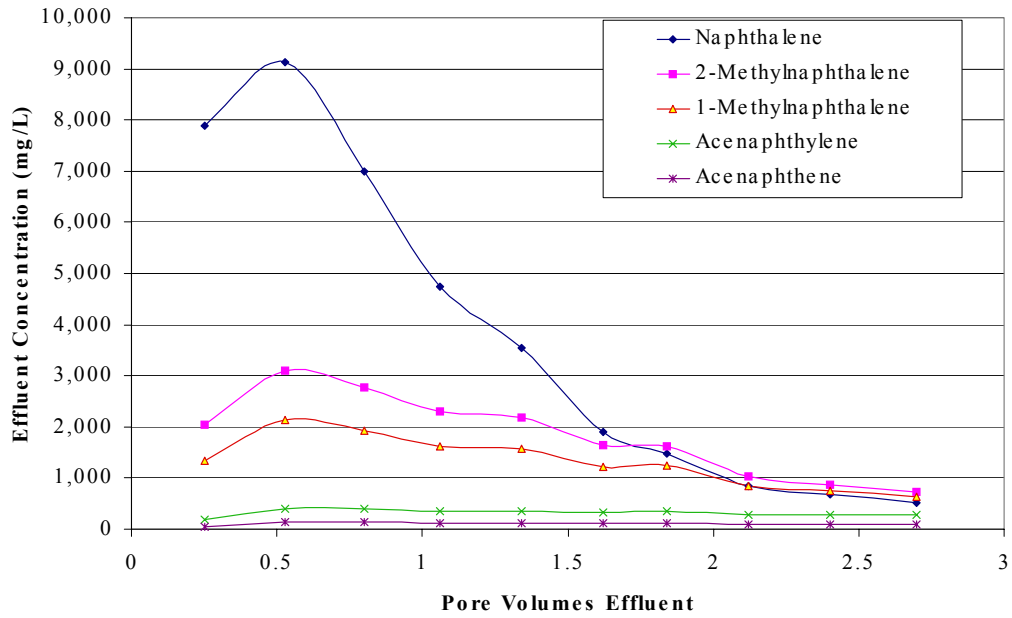


Figure 4: Concentrations of Less Volatile PAHs

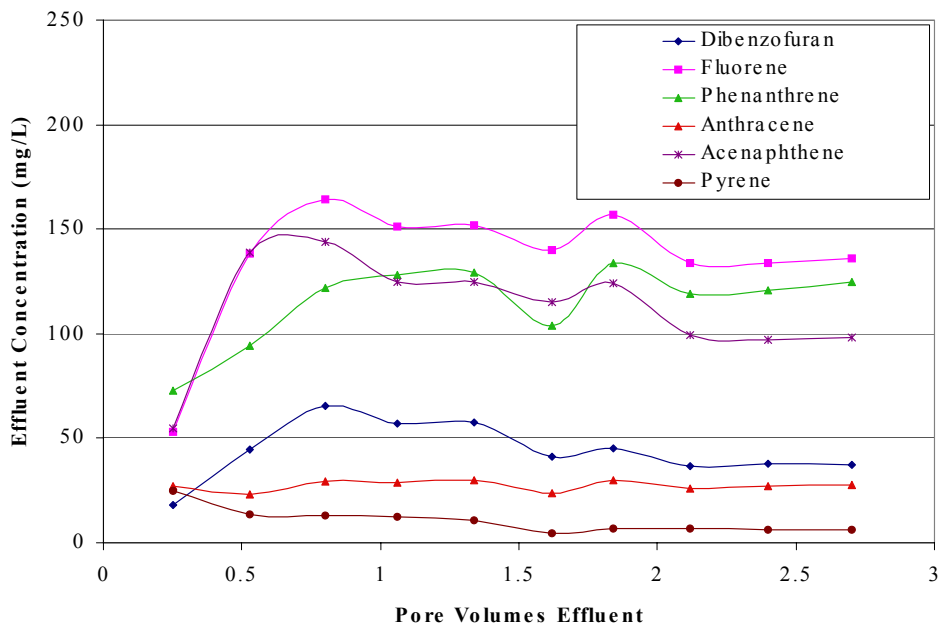
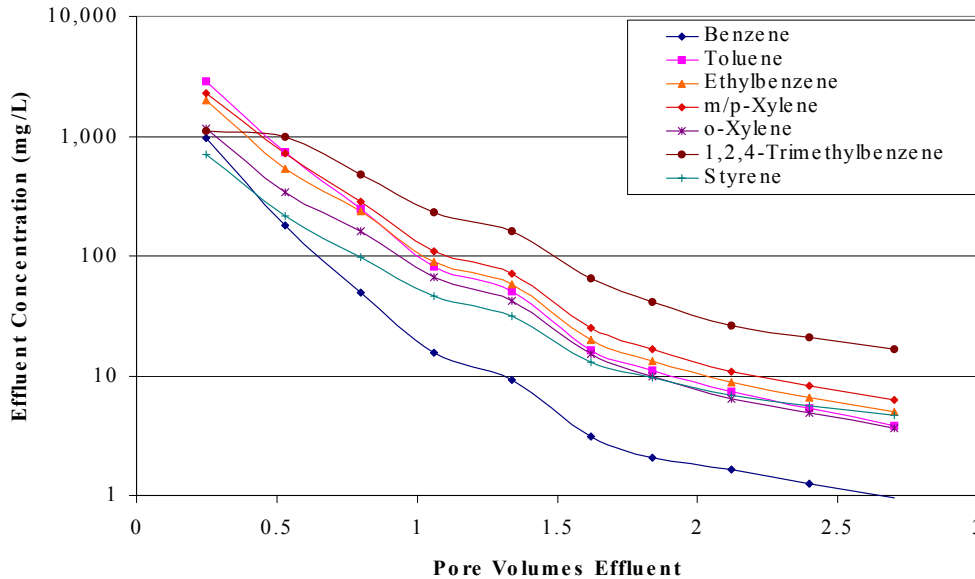


Figure 5: Concentrations of MAHs



The effluent concentrations of benzene, toluene, ethylbenzene, xylenes, 1,2,4-methylbenzene, and styrene obtained as a function of the number of pore volumes of effluent produced (Figure 5) clearly indicate that the more volatile components in the effluent decreased quite rapidly in the course of the experiment. These dramatic reductions are indicative of effective removal of these compounds from the hydrocarbon mixture.

Conclusion

This limited laboratory scale treatability experiment showed that the steam flow through the contaminated sand pack extracted several hydrocarbons most likely through vaporization of the more volatile constituents. However, the data also indicate that the high volatility compounds still remained in the sand matrix after the steam extraction experiment ended. The low volatility compounds remained in the soil matrix without much removal occurring by the applied steam. It is concluded that steam enhanced extraction alone is not likely to be sufficient to remove the majority of the coal tar mass. Presumably much higher temperatures could be more effective in removing the low volatility fractions of the coal tar as well as the readily volatilizable constituents.