PIPE EMISSIONS CALCULATIONS
Former Tidewater Facility
Pawtucket, Rhode Island

To estimate the emissions from the pipe during its removal at the Former Tidewater Facility ("the Site"), GZA GeoEnvironmental, Inc. (GZA) assumed that the air in the pipe was in equilibrium with the non-aqueous phase liquid (NAPL) in the pipe and that all of the air would be released from the pipe once removal began. These emissions were calculated using the following equations:

Total Pipe Emissions:

$$E = m_{i,Pipe\ Headspace} = C_{i,headspace} * V_{Pipe\ Headspace}$$

Where,
E = Total mass emitted from the Pipe in grams (g);
$V_{Pipe\ Headspace}$ = Volume of the Pipe's Headspace in cubic meters (m^3) (assumed to be 90% of 6-inch diameter pipe);
$m_{i,Pipe\ Headspace}$ = Amount of the Component i in the Pipe's Headspace in g;
$C_{i,headspace}$ = Concentration of Constituent i in Pipe's Headspace (g/m^3)

Ideal Gas Law:

$$\frac{n}{V_{Pipe\ Headspace}} = \frac{P_i}{R\,T}$$

$$C_{i,headspace} = \frac{n}{V_{Pipe\ Headspace}} * MW_i = \frac{P_i}{R\,T} MW_i$$

Where,
P_i = Partial Pressure of Component i in atmospheres (atm)[1];
n = Amount of the Component i in the Pipe's Headspace in moles (mol);
MW_i = Molecular Weight of the Component i in grams per mole (g/mol);
T = Temperature of Mixture in Kelvin (K); and
R = Universal Gas Constant in atmospheres cubic meters per Kelvin per mole (8.206E-05 atm*m^3/K/mol).

P_i is calculated by:

> For this scenario, the partial pressure was estimated using Raoult's Law using the constituent's concentration in NAPL.

> Raoult's Law:

$$P_i = P_i^* x_i$$

> Where,
> P_i = Partial Pressure of the Component i in the Mixture;
> P_i^* = Vapor Pressure of the pure Component i; and
> x_i = Mole Fraction of the Component i in the Mixture (moles component/total moles).

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[1] Note that because the impacts at the Site are not pure-phase, we have used the partial pressure as opposed to the vapor pressure of the pure component.

$$x_i = \frac{10^{-6}\ C_{i,Mixture}\ MW_{Mixture}}{MW_i}$$

Where,

10^{-6} = Conversion Factor of kilogram per milligram (kg/mg);

$MW_{Mixture}$ = Molecular Weight of Mixture in g/mol (assumed to be 250 g/mol); and

$C_{i,Mixture}$ = Concentration of Component i in the Mixture in milligrams of Component i per kilogram of Mixture (mg/kg) (the average measured constituent concentrations in NAPL located in wells on-Site was used).

We've conservatively assumed a NAPL temperature of 60°C in our calculations. We have therefore utilized the Clausius-Clapeyron equation to calculate vapor pressures at 60°C from those in the literature (typically 25°C):

Clausius-Clapeyron Equation:

$$\ln\left(\frac{P_1}{P_2}\right) = \left(\frac{\Delta H_{vap}}{R}\right)\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Where,

P_1 = Vapor Pressure at a Known Point;

P_2 = Vapor Pressure at a Given Point;

T_1 = Temperature at a Known Point in Kelvin (K);

T_2 = Temperature at a Given Point in K;

ΔH_{vap} = Enthalpy of Vaporization of Component i in kilojoules per mole (kJ/mol); and

R = Universal Gas Constant in kilojoules per Kelvin per mole (8.314E-03 kJ/K/mol).