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Nitrate/Sulfate Addition and Syntrophic Biodegradation:

Kickstarting Petroleum Biodegradation

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Nitrate/Sulfate Addition and Syntrophic Biodegradation: Kickstarting Petroleum Biodegradation

The remediation of petroleum- impacted sites in both active and monitored natural attenuation situations commonly relies on biodegradation. A large and diverse population of microbes is known to use petroleum hydrocarbons as a food source, forming the basis of bioremediation for these contaminants[1]. Petroleum biodegradation is fastest when microbes have an ample supply of oxygen, which is the most favorable electron acceptor from a redox standpoint. For this reason, oxygen is quickly depleted in most petroleum-impacted sites (Figure 1). One of the next-best electron acceptors is nitrate (NO_3^-) which is also rapidly utilized in groundwater when petroleum or other carbon sources are present. After oxygen and nitrate, several other electron acceptors, including iron and sulfate (SO_4^{2-}) may be used by microbes. As the more favorable electron acceptors are consumed, an aquifer will become methanogenic. Under these conditions the acetate, other small organic compounds, CO_2, and H_2 that are produced by syntrophic degradation of the petroleum hydrocarbons are ultimately converted to CH_4.

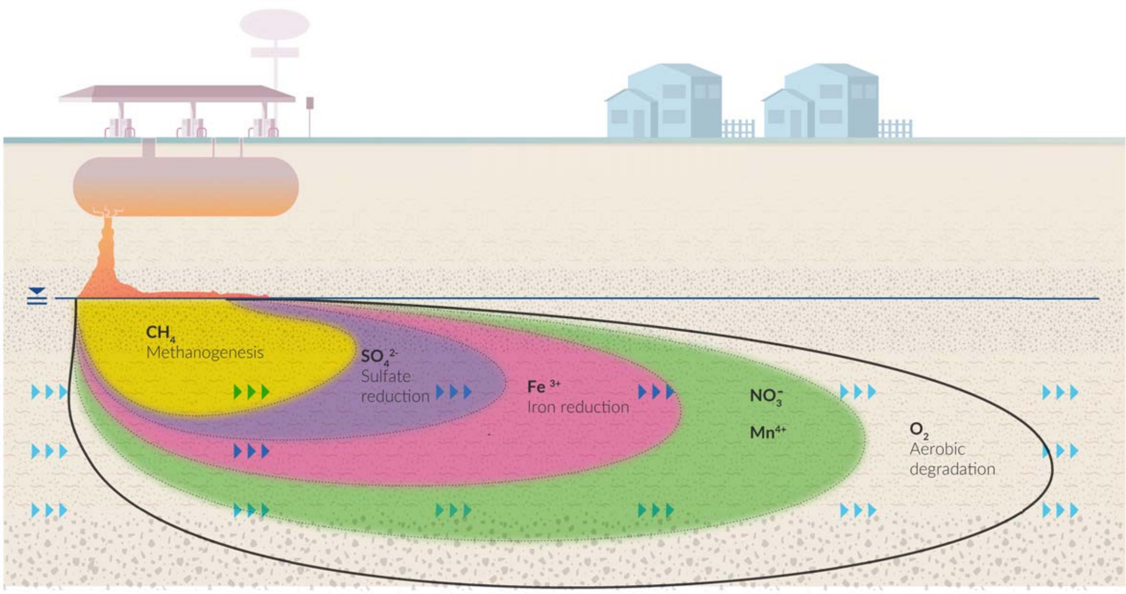


Figure 1. *Redox zones created by the depletion of electron acceptors in a common hydrocarbon plume. The order that petroleum degrading microbes utilize electron acceptors follows with their redox potential. Oxygen has the most positive redox potential and is therefore depleted first. Image adapted from https://toxics.usgs.gov/photo_gallery/photos/bimidji/bimidji4_lg.jpg*

The mineralization of petroleum contaminants using electron acceptors like oxygen requires a stoichiometric amount of the electron acceptor, which often is an impractical amount or necessitates follow-up injections. This limitation is true for PetroFix™ or almost any other remedial amendment on the market. However, the addition of non-stoichiometric amounts of nitrate or sulfate as electron acceptors can aid biodegradation, even after their consumption, by promoting syntrophy.

Furthermore, reports have demonstrated improved outcomes when both electron acceptors are used together as a result of the following benefits of co-application[2]:

1. Denitrifying bacteria remove benzene more rapidly compared to sulfate reducers alone. Because benzene is usually the petroleum contaminant with the lowest cleanup standard, this can be a significant advantage[3]

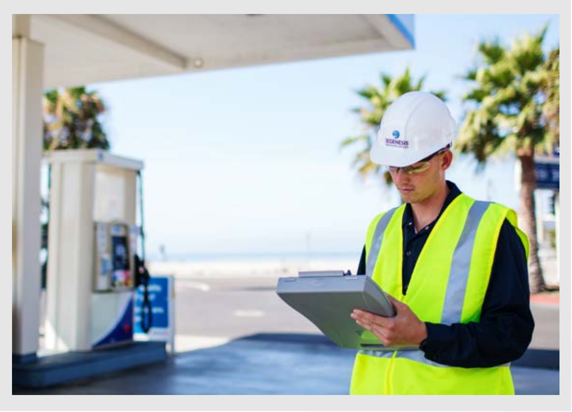
2. Sulfate reducers and denitrifying bacteria metabolize BTEX components in slightly different ways. Providing nitrate and sulfate stimulates both populations and promotes faster, more complete petroleum degradation.

3. Many of the syntrophic bacteria capable of reducing nitrate and sulfate will continue to thrive after the added electron acceptors are exhausted. Petroleum components will be fermented to acetate and hydrogen which are then removed by methanogens (see figure 2).

Syntrophic Metabolism

Syntrophy describes the process in which a community of microbes 'feed together', simultaneously using carbon sources and their byproducts in an ecological partnership[4].

A simplified illustration of syntrophy is shown in Figure 2. On petroleum-contaminated sites, BTEX and other hydrocarbons will be metabolized to acetate and hydrogen by syntrophs. This process can continue to occur so long as the produced hydrogen and acetate are removed by a community of methanogens. Under these conditions, contaminant degradation can proceed without the need for an additional electron acceptor. Researchers have shown that syntrophic arrangements are common and critical to the success of natural attenuation on many petroleum-impacted sites[5].



Syntrophic Metabolism - Continued

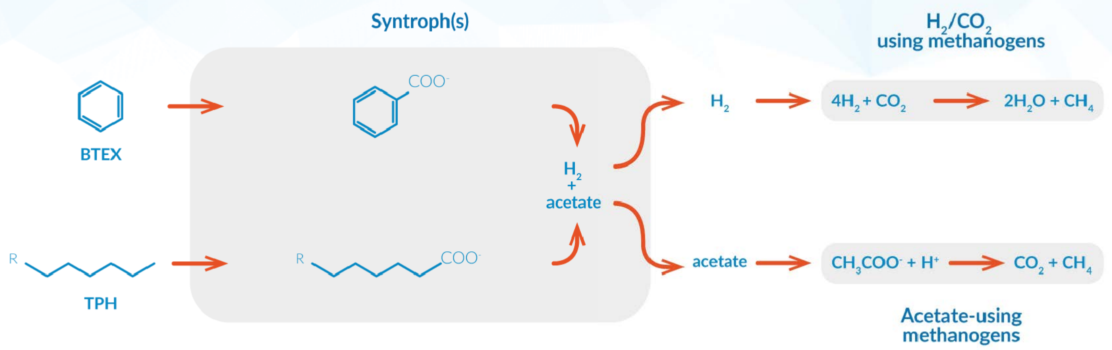


Figure 2 *Syntrophic metabolism on petroleum-impacted sites proceeds in two general steps. The first group of microbes metabolize BTEX and other hydrocarbons into simpler substrates like acetate and hydrogen (H_2). These metabolites are mineralized by subsequent microbes, which may be methanogens (shown) or reducers of other electron acceptors, when available. By working together, these microbes maintain an ecological balance that facilitates efficient petroleum degradation. Figure adapted from Ref 3.*

Conclusion

The remediation strategy employed when applying PetroFix is two-part: contaminants are adsorbed to the activated carbon and biodegradation is kickstarted through the addition of a sulfate/nitrate blend to stimulate the growth of syntrophic and BTEX-degrading microbes. After the added nitrate and sulfate are exhausted, petroleum degradation will continue via syntrophic processes, meaning the continuous addition of electron acceptors is not required. The combination of an injectable form of activated carbon that can adsorb contaminants and contain them in a finite zone with electron acceptors that will initially degrade the contaminants via anaerobic pathways and promote syntrophic conditions that sustain degradation will expedite the remediation of petroleum-impacted sites.

References:

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