Passive Above Ground Iron Filings Treatment of Contaminated Groundwater

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Abstract: A passive above ground iron filings treatment system has been developed to overcome the difficulties associated with the construction, monitoring, replacement/removal and unpredictable hydraulic tendencies of *in situ* iron filings permeable barriers. Contaminated groundwater is extracted from three artesian wells and distributed to multiple above ground containers holding iron filings. Iron filings, as a proven reactive media for the dehalogenation of volatile organic compounds (VOCs), are used as the primary treatment media. The combination of artesian pressure at the extraction wells and elevation drop between the wells and the treatment facility allows the entire system to function without the need for pumps. Hydrogen and other gases produced during dehalogenation are allowed to vent to the atmosphere. Ferrous iron that has gone into solution is precipitated out as ferric iron oxide as part of an pre-aeration treatment process. The iron oxide is then filtered out of solution by sand filters. Typical TCE destruction efficiency for the iron filings system is about 90%. This above ground iron filings treatment system combines the benefits of a conventional *in situ* reactive barrier with an *ex situ* facility. This allows for tight control of the process flow, accurate monitoring, convenient maintenance, and easy decommissioning.

Background: At Lawrence Livermore National Laboratory's remote testing facility in northern California, a confined aquifer is contaminated with trichloroethene (TCE) and nitrate. Three wells completed in this aquifer are artesian. The surface terrain is very hilly with steep slopes and narrow canyons. A study was conducted to determine the feasibility of installing a subsurface iron filings permeable barrier in this location. It was determined that the construction would be difficult and costly. The questionable long term remedial capacity and hydraulic properties, plus the difficulty in removal and/or replacement of the iron and lack of adequate monitoring techniques to quantify performance were also a concern. In light of these problems, deployment of a permeable iron filings wall was impractical. However, given the artesian nature of the wells and surface elevation differences, it was determined that an above ground treatment facility, requiring no additional power, could move contaminated water through containers filled with iron filings. The challenges was to balance the naturally available pressure head with the back pressure created by the treatment processes while maximizing the system's capacity to remove contaminant mass from extracted groundwater.

Bench Scale Studies: Studies were conducted under controlled laboratory conditions while simulating field specific parameters to observe the reaction of contaminated groundwater while flowing through iron filings. Four columns containing iron filings were placed in series with sampling ports and pressure gages between each column. Line pressures, recorded at various flow rates, were used to calculate hydraulic conductivity. Samples were collected to measure the effect of residence time on TCE reduction. The creation and subsequent reduction of cis-1,2-DCE was also observed. The average calculated hydraulic conductivity was 0.015 feet/minute. Plotting the decreasing TCE concentration against retention time and fitting the data with a first order exponential decay equation, $C=C_oe^{-kt}$, enabled the back calculation of the decay constant k which was 3.38 $hours^{-1}$. The TCE half-life was 12 minutes. This value corresponds with the

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results of an independent parallel study (Schreier 1999) which reported a TCE half life of 11 minutes using the same concentrations, iron and groundwater. Using this value it was determined that the required residence time to destroy 85% of the anticipated contaminants was about 34 minutes. The porosity of the iron filings supplied by Peerless™ was 0.56.

Design: The complete treatment system layout includes: filtration of fines, contaminant destruction by iron filings, residual volatile adsorption by granular activated carbon, iron oxide precipitation and removal by aeration and sand filtration and nitrate reduction by biological digestion (Figure 1).

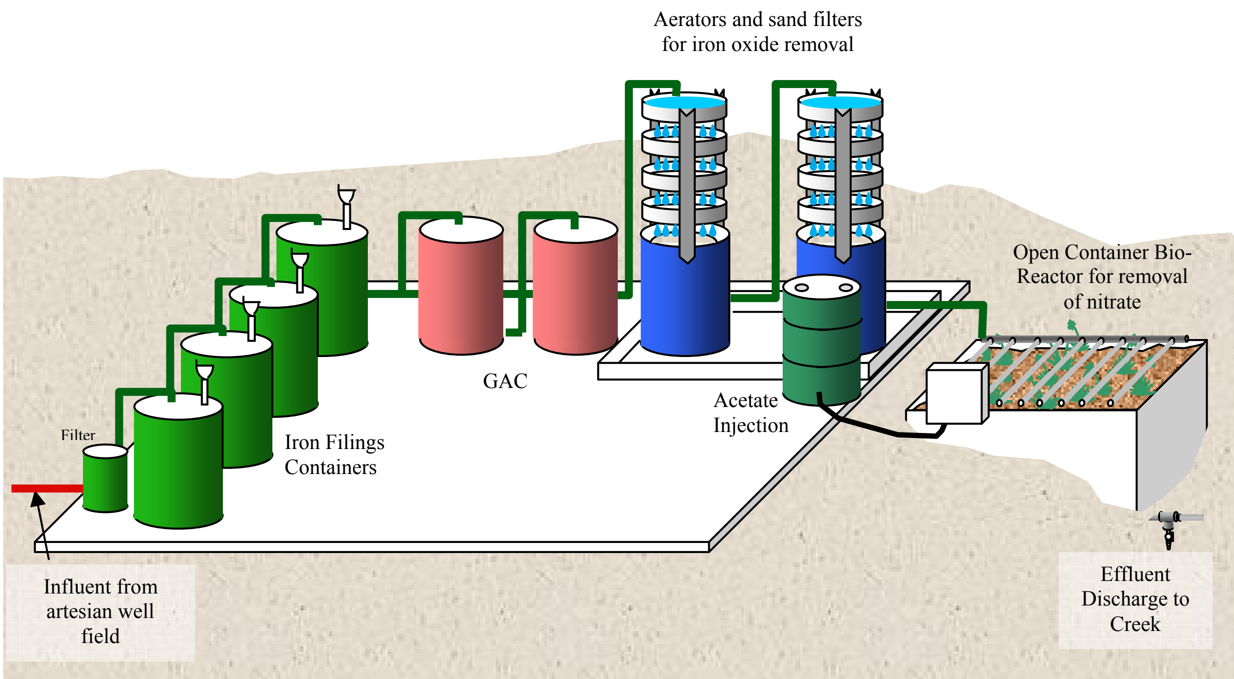

Figure 1- Passive above ground iron filings system

The iron filings containers are designed to withstand the artesian and elevation head pressures, promote uniform flow through the media, and minimize head loss. Four containers, holding about 4-1/2 cubic feet of iron filings each, are configured in parallel to minimize headloss. The flow is downward through the iron filings. Two 200 pound granular activated carbon (GAC) filters are installed after the iron filings to adsorb any residual VOCs.

During the chemical reaction within the iron containers, electrons are transferred from the iron to the chlorinated compounds in solution which liberates chlorine ions, hydrogen gas and eventually creates ethane (2 TCE(C_2HCl_3) + $16e^-$ + $10H^+$ ==> 2 ethane(C_2H_6) + $6Cl^-$). The iron is transformed to iron^{+2} ($3Fe^o$ ==> $3Fe^{+2}$ + $6e^-$) which may be dissolved in solution. Iron^{+2} may further oxidize to supply additional electrons (Fe^{+2} ==> Fe^{+3} + e^-). With ferrous ions in solution, there is always the possibility that when the solution is exposed to oxygen, the iron will come out of solution as orange oxide precipitate. Visual rust in a surface discharge is not desirable from a regulatory perspective. Precipitate can also dampen the efficiency of downstream treatment components. Aeration towers were designed to expose the process water to the atmosphere and filter out iron oxide precipitates prior to biological treatment and discharge.

The final phase of the treatment system is microbial denitrification using an Open Container Bio-Reactor (OCBR). The OCBR contains layers of granular materials including, from top to bottom, fine sand, coarse sand, aquarium grade gravel, lava rock and drainage gravel. The large surface area of the gravel and porous nature of the lava rock provides a habitat for denitrifying bacteria. The bacteria utilize nitrate in cellular respiration and reduce nitrate to nitrite, nitrous oxide and nitrogen gas. Nitrate reduction is limited by the supply of carbon and phosphate. Acetic (CH_3COOH) and phosphoric (H_3PO_4) acid are mixed into the flow stream by a venturi-type injector just prior to the OCBR. The size of the granular material, and thus the void dimensions, increase in the direction of water flow (down) allowing fines and excess bio-mass to more easily exit the reactor.

System Performance: The above ground iron filings treatment system has been operational since July 27, 2000 at a flow rate is 1 gal/min. Influent TCE concentrations have varied from 51 to 100 ppb. Influent nitrate concentrations have varied from 50 to 65 ppm. Effluent TCE concentrations from the iron filings containers have varied from <0.5 ppb to 25 ppb (65 to 99% destruction efficiency) when the system is functioning normally. Back calculation of the first order decay constant for TCE shows a range from 0.7 to 3.2 hr^{-1} for the system's performance in the field. This correlates to a TCE half life of between 15 minutes and one hour.

The primary maintenance issue is the removal of the iron oxide layer which develops on the leading surface of the iron filings. This layer, which is typically about 1/16 inches thick, causes the back pressure at the influent to the iron filings containers to increase from about 3 psi to over 12 psi in a matter of days. This low permeable layer can also cause short circuiting of the iron filings containers. Standing water in an iron filings container with an open lid will quickly disappear when this thin layer of rust is punctured by a small hole. Removing the thin layer of iron oxide returns the system to standard operational flows and pressures.

The ability to accurately control flow and monitor system parameters and efficiency has led to a greater understanding of the treatment process and has enabled continual improvement of the system operation. The ease of construction, maintenance, expansion, and decommissioning, combined with the absence of utility expenses, are important cost saving features of this passive, above ground system.

References

Schreier, C. G., Report of Findings-Bench-scale Evaluation of Zero-Valent Iron and Other Materials for Groundwater Remediation, PRIMA Environmental, Sacramento, CA (Unpublished), June 1999.