The potential of solid potassium permanganate as a horizontal permeable reactive barrier in unsaturated zone

Mojtaba Ghareh Mahmoodlu [a], S. Majid Hassanizadeh [a,b], Niels Hartog [b,c], Amir Raoof [a]
[a] Utrecht University, Department of Earth Sciences, The Netherlands
[b] Soil and Groundwater Systems, Deltares, Utrecht
[c] KWR Watercycle Research Institute, Nieuwegein, The Netherlands

1. Introduction:

Volatile organic compounds (VOCs) are present in some household products and automobile liquids (Berscheid et al., 2010). Releases of VOCs to the environment have occurred through surface spills, leaking underground storage tanks, and inadequate disposal practices (Berscheid et al., 2010). When released as free product, VOCs may migrate downward to significant depths through the soil. In addition, VOC vapours can migrate upwards to the surface through diffusion and produce elevated concentrations within indoor air spaces (Berscheid et al., 2010). Exposure to some VOCs might affect central nervous system and internal organs, and might cause symptoms such as headache, respiratory tract irritation, dizziness and nausea, known as the Sick Building Syndrome (SBS) (Yu, and Lee, 2007).

We have chosen TCE, ethanol, and toluene, as model VOCs (target compounds) for chlorinated solvents, biofuel, and mineral oil, respectively.

Early laboratory studies have indicated that dissolved potassium permanganate can remediate a variety of organic compounds. However, the potential of solid potassium permanganate to oxidize VOC vapours in unsaturated zone is currently unknown.

In this study, we demonstrate the ability of solid potassium permanganate as horizontal reactive permeable barrier to oxidize TCE, ethanol, and toluene in both gas and aqueous phases.

2. Motivation

2.1. What is the problem?

Migration of VOC vapours upward to the indoor spaces.

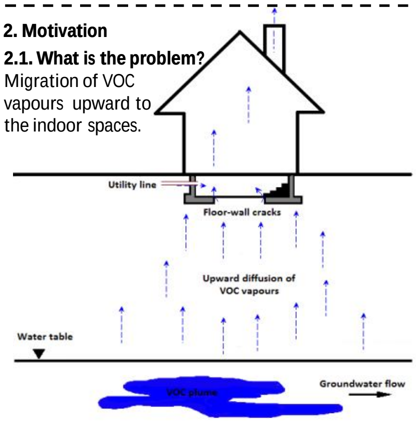

Fig.1: Conceptual model for vapour intrusion.

2.2. What is the idea?

Creating a horizontal reactive permeable barrier in unsaturated zone using $KMnO_4$.

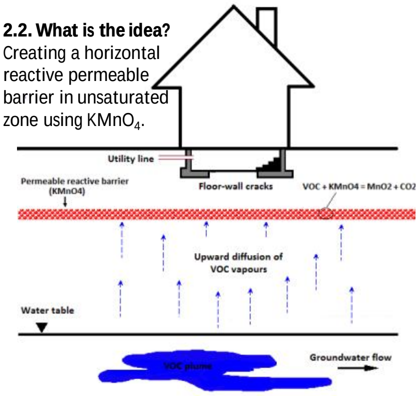

Fig.2: A schematic view of a horizontal reactive permeable barrier.

3. Experiments and results

3.1. Batch experiment for gas phase

3.1.1. Experiment

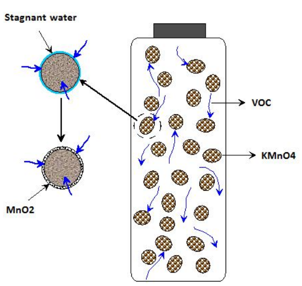

Fig.3: A schematic view of batch exp.

3.1.2. Reaction rate law

$$\frac{dC}{dt} = -kCS \quad (1) \qquad S = \frac{A}{V_{gas}} \quad (2)$$

k : the reaction rate constant
C : the vapour concentration of compound [ML^{-3}]
t: is time [T]
S: is the relative surface area of solid potassium permanganate [L^{-1}]
A : the surface area of KMnO4 [L^2]
V: the volume of the gas phase [L^3]

With S set equal to S_0 , Equation 1 can be solved to obtain:

$$\frac{1}{S_0} Ln \frac{C}{C_0} = -kt$$

3.1.3. Results

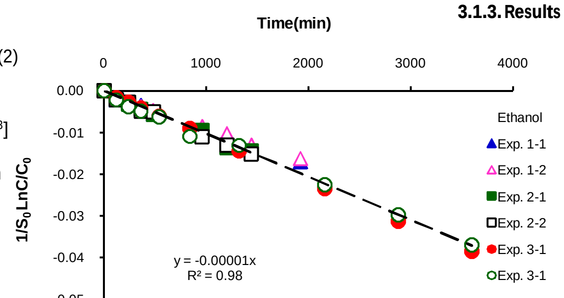

Fig. 4: Plot of $1/S_0 LnC/C_0$ vs. time for evaluating k. Three different combinations of initial vapour concentration of ethanol and relative surface area of $KMnO_4$ were used.

Table 1: Reaction rate constants in vapour phase at 20 °C

VOC	K($cm\ min^{-1}$)
TCE	1.2×10^{-4}
Ethanol	1.0×10^{-5}
Toluene	4.2×10^{-6}

3.2. Column experiment without flow

3.2.1. Experiment

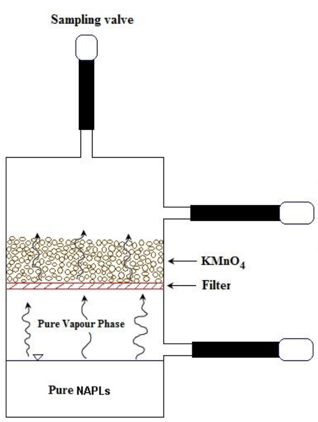

Fig. 5: Schematic drawing of the column.

3.2.2. Simulation results

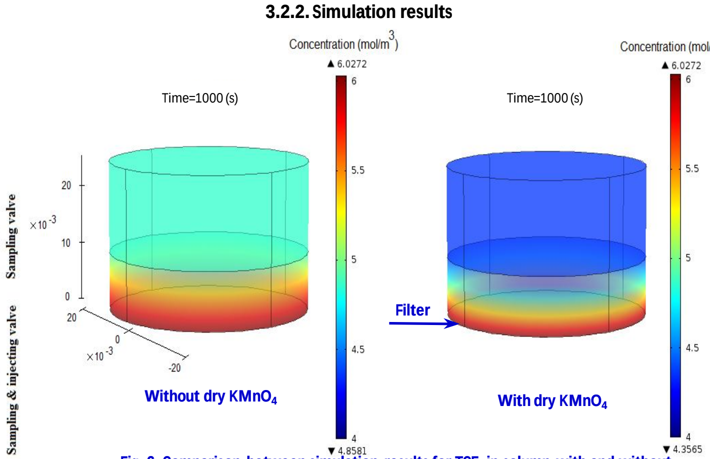

Fig. 6: Comparison between simulation results for TCE in column with and without dry $KMnO_4$.

3.2.3. Results

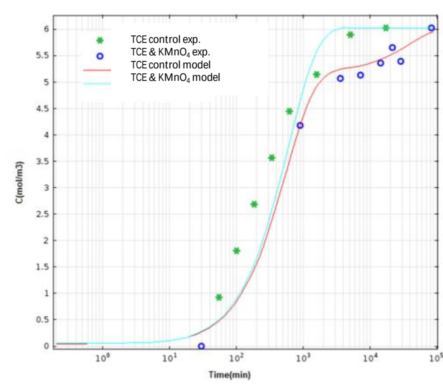

Fig. 7: Experimental and simulation results for TCE using dry $KMnO_4$.

3.3. Column experiment with flow(Current work)

3.3.1. Experimental set up

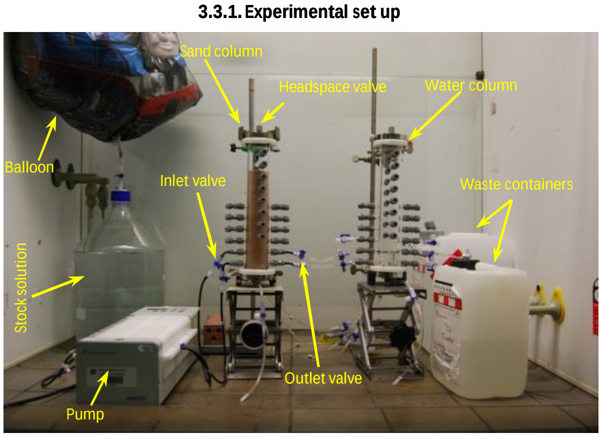

Fig. 8: Experimental set-up for the column with flow.

3.3.2. Preliminary simulation results

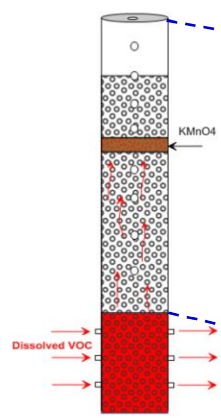

Fig. 9: A schematic view of the column with flow.

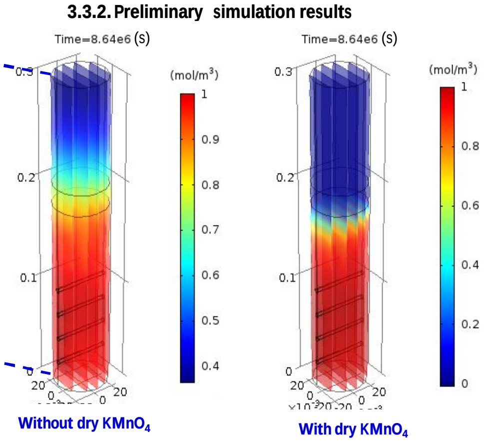

Fig. 10: Preliminary simulation results for TCE showing the effect of dry $KMnO_4$ on the oxidation of TCE vapour.

References:

1. Berscheid, M., Burger, K., Hutchison, N., Muniz-Ghazi, H., Renzi, B., Ruttan, P., Sterling, S., 2010. Proven Technologies and Remedies Guidance: Remediation of Chlorinated Volatile Organic Compounds in Vadose Zone Soil. California Department of Toxic Substances Control. 154 pp.
2. Mahmoodlu M.G., Hartog N., Hassanizadeh S.M., Raoof A., 2013, Oxidation of volatile organic vapours in air by solid potassium permanganate, journal of Chemosphere.
3. Yu, K.P., Lee, G.W.M., 2007. Decomposition of gas-phase toluene by the combination of ozone and photocatalytic oxidation process (TiO_2/UV, TiO_2/UV/O_3, and UV/O_3). Appl. Catal. B: Environ., 75, 29-38.