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Effect of temperature on removal of trace organic chemicals in managed aquifer recharge systems

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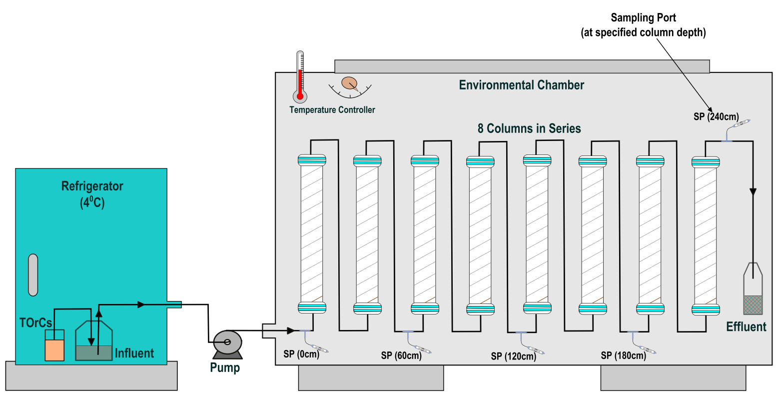
HIGHLIGHTS

- Attenuation of most TOrCs is unaffected by temperature changes within 4–30 °C.
- Biodegradable TOrCs exhibit increased removal at higher temperatures.
- TOrCs attenuated by sorption exhibit increased removal at lower temperatures.
- Seasonal temperature changes in MAR systems are not considered to be of concern.

GRAPHICAL ABSTRACT



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ABSTRACT

This study was undertaken to investigate whether changes in temperature experienced in MAR systems affect attenuation of trace organic chemicals (TOrCs). A set of laboratory-scale soil columns were placed in a temperature-controlled environmental chamber and operated at five different temperature set-points (30, 20, 10, 8 and 4 °C) covering the range of typical groundwater temperatures in cold, moderate and arid climate regions. Removal of bulk organic carbon both in the infiltration zone as well as during deeper infiltration was independent of temperature. Of the 22 TOrCs investigated, only six chemicals exhibited changes in attenuation as a function of temperature. Attenuation of four of the compounds (diclofenac, gemfibrozil, ketoprofen and naproxen) decreased as the temperature was reduced from 30 °C to 4 °C, likely due to decreased microbial activity at lower temperatures. As the temperature was decreased, however, attenuation of oxybenzone and trimethoprim were noted to increase. This increased attenuation was likely due to more efficient sorption at lower temperatures, though possible changes in the microbial composition as the temperature decreased may also have contributed to this change. Changes in rate constants of attenuation (k_a) for the biotransformed TOrCs with temperature suggested the existence of a critical temperature at 10 °C for three of the four TOrCs, where significant changes to rates of attenuation occurred. Results from this study indicated that for most TOrCs, changes in temperature do not impact their attenuation. Thus, seasonal changes in temperature are not considered to be a major concern for attenuation of most TOrCs in MAR systems.

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1. Introduction

Greater water demands globally due to increasing populations and limited water resources in many regions, has led to managed aquifer recharge (MAR) becoming an important method to sustain groundwater resources. MAR including processes such as riverbank filtration (RBF), soil aquifer treatment (SAT) and aquifer recharge and recover (ARR) have been in use for many years in different parts of Europe and the United States (Irmscher and Teermann, 2002; Laws et al., 2011; Missimer et al., 2011) either as a pre-treatment step in drinking water schemes or as a post-treatment step in wastewater reuse schemes. MAR is also being considered in water scarce regions such as Saudi Arabia as part of a multiple barrier approach for water reclamation schemes (KICP, 2012). MAR systems have been shown to be capable of removing organic carbon, total nitrogen, pathogens such as bacteria and viruses and even a range of trace organic chemicals (Quanrud et al., 2003; Amy and Drewes, 2007; Maeng et al., 2011) .

Trace organic chemicals (TOrCs) encompassing pharmaceuticals and personal care products, pesticides, household chemicals, endocrine disrupting chemicals have been detected both in wastewater effluents and surface water reservoirs around the world (Focazio et al., 2008; Benotti et al., 2009; Pal et al., 2010). They typically occur at very low concentrations and human health risk assessments have reported that adverse health impacts with exposure to these concentrations are unlikely (DWI, 2007; AwwaRF, 2008). Nevertheless, TOrC removal is desired since their presence in surface water and groundwater indicate wastewater impact.

Although only a few TOrCs in water are regulated currently, others may be candidates for future regulation considering their potential adverse health effects and widespread occurrence in various environmental compartments (Jones-Lepp, 2007). Employing multiple expensive advanced treatments processes such as ozonation, membranes and activated carbon specifically for TOrC removal may be effective (Asano and Cotruvo, 2004), but usually come at higher capital and O&M costs. MAR systems often considered as an advanced treatment process (Amy and Drewes, 2007) stand out due to their ability to attenuate a range of TOrCs with much lower cost, energy consumption, chemical usage and carbon footprint.

Numerous processes have been reported to affect fate and transport of TOrCs in MAR systems such as advection, diffusion, adsorption and microbial degradation (Benotti and Snyder, 2009). Of these, microbial transformation is the dominant process for most TOrCs especially for compounds which exhibit little or no sorption. The microbial community in the soil is subject to many subsurface and operational conditions such as nature of the primary substrate, redox conditions, wet–dry cycles as well as external factors such as ambient temperature (Maeng et al., 2011).

It is important to consider the effect of temperature since Europe, Australia, the Middle East and the United States where MAR is implemented regularly, experience large seasonal variations of temperature. Climate change has resulted in impacts on weather with the greatest impacts being rising temperatures and an increased occurrence of weather extremes (IPCC, 2007). Temperature and precipitation in particular have been identified as being the two main climatic factors affecting bank aquifer recharge performance (Sprenger et al., 2011). Vulnerability to changes in temperature is expected for a natural system like MAR, justifying an in-depth study into how this affects its performance particularly in relation to TOrC attenuation.

Field studies in different locations investigating TOrC attenuation during managed aquifer recharge, often report varying removal efficiencies for different compounds (Drewes et al., 2003; Heberer and Mechlinski, 2004). This is not entirely unexpected since ambient and subsurface conditions can vary considerably from one site to another and dilution effects may be difficult to quantify. Laboratory studies where many operational conditions can be kept constant provide useful insights into the effects of certain variables on TOrC attenuation. A controlled laboratory approach was hence undertaken in this study utilizing soil columns to investigate effect of temperature changes on TOrC attenuation.

2. Materials and methods

2.1. Soil column setup

The column setup consisted of eight columns (GE Healthcare XK 50/30 glass columns, Sweden; length: 30 cm, internal diameter: 5 cm) connected in series. The columns were in operation for more than 15 months prior to commencement of this experiment representing an active microbial community. Pre-treated native soil collected upstream of a wastewater discharge from Wadi Wajj in Saudi Arabia and sieved to retain the fraction below 2 mm had been used to fill the columns. The soil was washed with deionized water and transferred into the columns totally submerged in water to minimize introduction of any air bubbles. The soil filled in the columns has been previously characterized (Alidina et al., 2014b) as having low organic matter content with f_{oc} of 0.10 ± 0.01%. The hydraulic conductivity was determined to be 0.070 ± 0.006 cm s^{-1}, while the porosity was 0.32 ± 0.03.

The columns were operated in saturated up-flow mode. A tracer test was performed at room temperature by feeding a conservative tracer (potassium bromide, KBr) through a single column for a period of 6 h, after which the feed was switched to DI water for an additional 44 h. Effluent samples were collected every 30 min using a fraction collector and analyzed using a Dionex Ion Chromatography ICS-1600 variable wavelength detector (VWR) system (Sunnyvale, CA) according to Standard Method 4110C. The hydraulic retention time calculated using the method of moments was determined to be 19.7 h per column, giving a total hydraulic retention time through the series of eight columns of 158 h (6.5 d).

The column setup was placed inside a Thermo Scientific Forma Environmental Chamber (Model 3940; Marietta, OH) with an operating range of 0–60 °C. The environmental chamber fitted with a digital electronic controller allowed temperature transitions of 0.1 °C. The columns were operated at five temperature set-points (30, 20, 10, 8 and 4 °C) with a minimum duration of 9 weeks at each temperature set-point. These temperature set-points covered the entire range of temperatures typically expected in groundwater and spanning the extremes of 3 °C and 26 °C observed in shallow and deep groundwater monitoring wells (Lee and Hahn, 2006). A temperature of 30 °C was selected as the upper temperature set-point in order to minimize any sustained damage on enzymes due to denaturation at elevated temperatures.

The temperature set-point was defined as the temperature in the effluent collected after flow through the columns. Achieving the target temperature required some adjustment from the displayed temperature of the environmental chamber. Weekly temperature readings of the effluent were taking to ensure minimal deviation from the set-point. Flow rate measurements were carried out at each temperature set-point. The maximum difference in flow rate of 3% observed between the different temperature set-points was not deemed to be significant, and hence no changes in pump flow rates were implemented. Additionally, tracer tests were performed with KBr at the two temperature extremes of 4 °C and 30 °C, verifying that the changes in water viscosity with a change in temperature did not affect the retention time.