



Influence of Water Table Fluctuation on Natural Source Zone Depletion in Hydrocarbon Contaminated Subsurface Environments

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ABSTRACT

Most of the prediction theories regarding dissolution of organic contaminants in the subsurface systems have been proposed based on the static water conditions; and the influence of water fluctuations on mass removal requires further investigations. In this study, it was intended to investigate the effects of water table fluctuations on biogeochemical properties of the contaminated soil at the smear zone between the vadose zone and the groundwater table. An automated 60 cm soil column system was developed and connected to a hydrostatic equilibrium reservoir to impose the water regime by using a multi-channel pump. Four homogenized hydrocarbon contaminated soil columns were constructed and two of them were fully saturated and remained under static water conditions while another two columns were operated under water table fluctuations between the soil surface and 40 cm below it. The experiments were run for 150 days and relevant geochemical indicators as well as dissolved phase concentrations were analyzed at 30 and 50 cm below the soil surface in all columns. The results indicated significant difference in terms of biodegradation effectiveness between the smear zones exposed to static and water table fluctuation conditions. This presentation will provide an overview of the experimental approach, mass removal efficiency, and key findings.

Keywords: Water table fluctuation; Hydrocarbon degradation; Biodegradation

1 INTRODUCTION

Groundwater is one of the most valuable natural resources available on earth. Its existence is vital to life and a fundamental part of our natural environmental cycles of carbon, nitrogen, oxygen, water and nutrients. Accidental spills of petroleum products, such as crude oil, gasoline, and diesel fuel are a common source of groundwater contamination especially in coastal areas. With the development of petroleum industry, petroleum hydrocarbons have become one of the widest spread pollutants. Contamination by crude oil poses serious social, economic and environmental problems worldwide as they gradually change the composition of soil and groundwater. The pollution by organic compounds affects the nature of plants and animals, and human health (Newton, 1990; Zhou, 1995).

When a non-aqueous phase liquid (NAPL) distributes in the subsurface systems, a hot spot will be created at the smear zone between the vadose zone and the groundwater table that is exposed to groundwater fluctuations. The transition zone separating soil from water table is a dynamic part of groundwater contamination. The fluctuations of water table driven by seasonal changes in recharge and discharge or by sea elevation in coastal environments cause temporal differences in local redox conditions (Haberer et al., 2012; Rezanezhad et al., 2014). The NAPL distribution in soil and groundwater is affected by different parameters such as the volume of non-aqueous phase liquid (NAPL), magnitude and speed of water table, the soil media, and fluid properties (Dobson et al., 2007; Oostrom, 2007). The objective of this work is to address the relation between the water table fluctuations on the hydrological and biogeochemical processes, which influence the degradation and mobilization of petroleum hydrocarbons, under conditions relevant to coastal aquifers in the semi-arid environments.

2 MATERIAL AND METHODS

The setup of the experiment contained four soil columns. Two of them were fully saturated under static condition while the other two soil columns were under water table fluctuations. All columns were made of hard acrylic (length is 60 cm, inner diameter is 7.5 cm, wall thickness is 0.6 cm). The water level in the soil columns was controlled by changing the water level in an equilibrium column. One equilibrium column controlled the water level in static soil columns (identified as static1 and static2) and each of the fluctuation columns (identified as fluc1 and fluc2) were separately connected to an equilibrium column. Each equilibrium column was connected to one Tedlar bag as the water storage. A multi-channel pump (9-channel Tower II pump, CAT. M. Zipperer, GmbH) was used to transfer water from the Tedlar bags to the equilibrium columns.

The soil for this experiment was collected from Simaisma beach in the northeast side of Doha, Qatar. The soil was synthetically contaminated by Toluene and Naphthalene following Brinch et al., 2002. Water table regime for the two static columns was maintained at the top of the soil surface (no change). While for the other two columns (fluctuating), an oscillating water table regime was imposed (fluctuating water table). The water level fluctuated between the soil surface (0 cm) and 40 cm below the soil surface, with an imbibition/drainage period lasting for 2.5 days and then 1 day under static conditions.

Aqueous samples were collected through two ports at the middle (30 cm below soil surface) and at the bottom (50 cm below soil surface). Each week samples were collected and analyzed for the concentrations of organic compounds, sulfate, and dissolved inorganic carbon (DIC) followed by the measurement of Eh, pH, DO and EC.

3 RESULTS AND DISCUSSION

The soil oxidation–reduction potential (ORP) is influenced by water table fluctuation unlike the static water table. The dissolved oxygen in all columns indicated a reduction after 20 days of the beginning of the experiment. The ORP of the 4 columns is illustrated in Figure 1. In the static water columns, ORP reduced with time from around 250 mv at the beginning of the experiment at both -30 and -50 cm and reduced to around 114 mv after 100 days. While for the fluctuating columns, values reduced from 300 mv at

the beginning of the experiment at -30 and -50 cm and reduced to 100 mv. In the static columns, ORP at -30 and -50 was approximately the same from the beginning till 100 days of the experiment for both columns. However, for the fluctuating columns, ORP at -50 cm was slightly lower than ORP at -30 cm at the beginning of the experiment, but after 60 days, ORP at the -5 and -30 were intersecting. This reduction in ORP is a strong indication of the reducing condition inside the columns although it does not reach to a negative value.

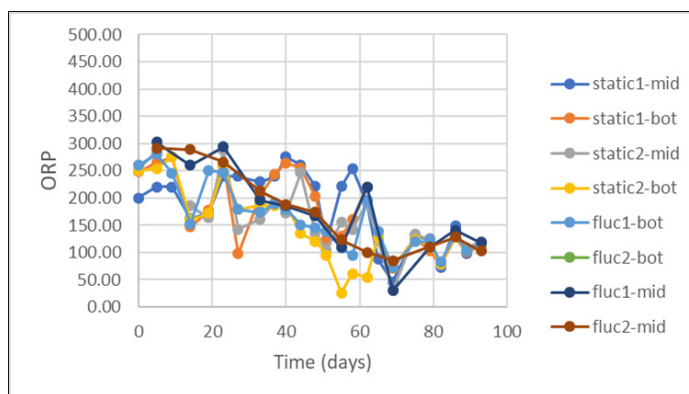


Figure1: ORP values from the middle (mid) and bottom (bot) of the columns under static conditions (static1 and static2) and under water table fluctuation condition (fluc1 and fluc2).

Significant change on the concentration of sulfate is observed in Figure 2. For the static 1 and 2 the concentration at -30 cm was reduced from 450, 330 mg/L to 165, 135 mg/L, respectively. Similarly, the sulfate concentration at -30 cm for the fluctuation 1 and 2 was reduced from 345, 325 mg/L to 230, 215 mg/L respectively. While for the bottom part (-50) of fluctuation 1 and 2, the concentration was reduced from 220, 295 mg/L to 130, 130 mg/L respectively. In general, the reduction percentage of sulfate in static columns (-30), fluctuating (-30), fluctuating (-50) was ~60%, ~ 33%, and 45%, respectively. The sulfate-reducing bacteria obtained energy by oxidizing organic compounds that exist in petroleum hydrocarbon while reducing sulfate (SO_4^{2-}) to hydrogen sulfide (H_2S). The reduction in sulfate concentration in the columns was expected as a result of sulfate reducing bacteria being enhanced and activated.

Toluene concentrations are presented in Figure 3, the results showed no change in concentration due to the large organic mass in soil. Another reason could be that the microbial community in the soil was still undeveloped.

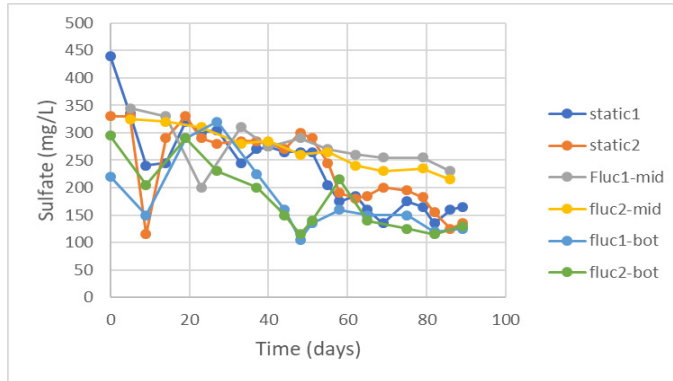


Figure 2: Dissolved sulfate concentrations in the middle of the columns under static conditions (static1 and static2) and from the middle (mid) and bottom (bot) of the columns under water table fluctuation condition (fluc1 and fluc2).

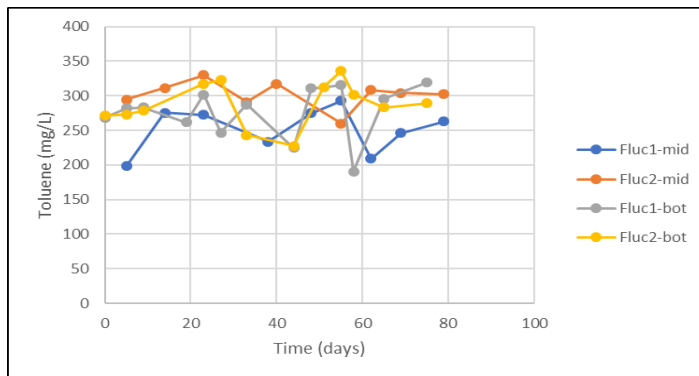


Figure 3: Dissolved toluene concentrations in the middle and bottom of the columns under water table fluctuation conditions (fluc1 and fluc2).

4 CONCLUSION

In this study, the variation in petroleum hydrocarbon concentrations (toluene and Naphthalene) due to water table fluctuation and degradation were experimentally studied. The results showed that, the degradation of toluene was occurring in both static and fluctuation columns. Sulfate consumption was a strong indication of anaerobic hydrocarbon degradation under the experimental conditions.

The results indicate that there is a significant variation in the redox potential and microbial activities at the smear zone under water table fluctuation conditions. While similar sulfate concentrations were observed in the static columns and the bottom parts of the fluctuating column, at the middle of the water fluctuation columns sulfate concentrations were higher. This can result in enhanced microbial community and biodegradation that could be attributed to the sulfate mobilization as well as sulfur oxidation during fluctuation process.

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