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# Soil aquifer treatment of artificial wastewater under saturated conditions

H.M.K. Essandoh [a], C. Tizaoui [b], M.H.A. Mohamed [a,*], G. Amy [c,d], D. Brdjanovic [c]

[a] School of Engineering Design and Technology, University of Bradford, BD7 1DP, UK
[b] College of Engineering, Swansea University, SA2 8PP, UK
[c] UNESCO-IHE, Westvest 7, 2611 AX Delft, The Netherlands
[d] Water Desalination and Reuse Center, King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia

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ABSTRACT

A 2000 mm long saturated laboratory soil column was used to simulate soil aquifer treatment under saturated conditions to assess the removal of chemical and biochemical oxygen demand (COD and BOD), dissolved organic carbon (DOC), nitrogen and phosphate, using high strength artificial wastewater. The removal rates were determined under a combination of constant hydraulic loading rates (HLR) and variable COD concentrations as well as variable HLR under a constant COD. Within the range of COD concentrations considered (42 mg $L^{-1}$–135 mg $L^{-1}$) it was found that at fixed hydraulic loading rate, a decrease in the influent concentrations of dissolved organic carbon (DOC), biochemical oxygen demand (BOD), total nitrogen and phosphate improved their removal efficiencies. At the high COD concentrations applied residence times influenced the redox conditions in the soil column. Long residence times were detrimental to the removal process for COD, BOD and DOC as anoxic processes and sulphate reduction played an important role as electron acceptors. It was found that total COD mass loading within the range of 911 mg $d^{-1}$–1780 mg $d^{-1}$ applied as low COD wastewater infiltrated coupled with short residence times would provide better effluent quality than the same mass applied as a COD with higher concentration at long residence times. The opposite was true for organic nitrogen where relatively high concentrations coupled with long residence time gave better removal efficiency.



## 1. Introduction

The importance of adequate sanitation as well as the availability of enough quantities of fresh water for human consumption and industrial and agricultural use cannot be underestimated as they play a vital role in maintaining a healthy livelihood and in the development of nations. As populations continue to increase with their associated problems of waste generation and increased contamination of surface and ground waters, pressure on available water resources is increasing. This, coupled with uneven distribution of water resources and periodic droughts around the world, has brought about the need for innovative sources of water supply and local conservation. Highly treated wastewater effluents from municipal wastewater treatment plants are therefore now increasingly being considered as a reliable source of water supply (Metcalf and Eddy et al., 2003).

* Corresponding author. Tel.: +44 (0)1274 233856; fax: +44 (0)1274 234111.
E-mail address: m.h.a.mohamed@bradford.ac.uk (M.H.A. Mohamed).
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Soil aquifer treatment (SAT) has been found to be a low-cost sustainable tertiary wastewater treatment technology, which has the ability to generate high quality effluent from secondary treated wastewater for potable and non-potable uses (Cha et al., 2006; Fox et al., 2006). During SAT, the saturated and unsaturated zones of the natural soil and groundwater aquifer act as the medium in which physicochemical and biological reactions occur (Cha et al., 2006). These reactions substantially reduce the levels of organic and inorganic compounds including nitrogen, phosphorus, suspended solids, pathogens and heavy metals leading to an improvement in water quality (Pescod, 1992; Bdour et al., 2009). Mixing of the infiltrated wastewater with the groundwater and the slow movement through the aquifer increases the contact time with the aquifer material leading to further purification of the water (Asano and Cotruvo, 2004; Dillon et al., 2006). Besides treatment, SAT offers the opportunity of aquifer recharge (Droste, 1997) thus seasonal or long-term storage of water can be achieved (Fox et al., 2006), which is especially beneficial in arid areas.

The unsaturated zone is characterized by availability of oxygen as well as increased ability of flow of air during the drying period of the SAT treatment cycle. Existence of oxygen in the unsaturated zone is highly important in promoting aerobic biodegradation processes and nitrification. Factors influencing the efficiency of SAT include characteristics of treatment site, soil and wastewater characteristics, climate and infiltration rate (TanIk and Çomakoglu, 1996). Redox conditions and residence time can have a significant influence on the kinetics of dissolved organic carbon (DOC) degradation (Grünheid et al., 2005) and may affect the removal efficiency. In the saturated zone, where a greater portion of the residence time occurs (Fox and Makam, 2009), dissolved oxygen is limited and the level of contaminants in the infiltrating wastewater and associated oxygen demand may have a major impact on the efficiency of the removal process.

Although a large number of SAT systems exist, most of them involve well-treated effluents of low organic content and utilize the vadose zone. So far, limited work has been done to demonstrate the applicability and practicality of using SAT in treating poorly treated effluents or even primary effluents. In addition, complete reliance on the saturated zone without utilisation of the vadose zone in the treatment has never been explored. Earlier studies carried out found a correlation between the organic and hydraulic loading rates and effluent quality (Nema et al., 2001). It was observed that effluent biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), total kjeldahl nitrogen (TKN), ammonia nitrogen ($NH_3$) and phosphorus concentrations increased linearly with an increase in cumulative mass loading. Effluent quality with respect to these parameters was also found to deteriorate linearly with increase in cumulative hydraulic loading (Nema et al., 2001). These results were however found to be contradictory to previous studies indicating that the hydraulic loading was a more important operating parameter than the organic loading in determining the effluent quality (Carlson et al., 1982). These studies involved an unsaturated zone for the treatment and in recent years no further studies have been carried out. This paper presents results of the experimental investigation using a 2 m long soil column with a particular focus on the removal of BOD, DOC, COD, nitrogen and phosphate in the saturated zone. In addition, the influence of hydraulic loading rates on the treatment efficiency of wastewater of much higher COD than normally encountered in secondary or tertiary effluents applied in SAT systems was studied.

## 2. Materials and methods

### 2.1. *Soil column description and setup*

Fig. 1 shows a schematic drawing of the soil column setup. The column used for this study was made of acrylic tube with an inner diameter of 140 mm and length 2000 mm. Flanges were fitted to the top and bottom of the column for attachment of the top and bottom end caps. Two holes were provided in the top cap. One served as the column exit and the other was fitted with a valve for bleeding air out of the column. A 10 mm thick PVC distributor cut out in the form of a labyrinth was mounted on the inner surface of bottom cap to facilitate even distribution of water over the entire cross section of the column. To maintain a watertight seal, a gasket was placed between the tube and the end caps before securing them together. Water sampling points consisting of 3.2 mm inner diameter stainless steel tubes were provided at ten points (100 mm, 200 mm, 300 mm, 400 mm, 500 mm, 600 mm, 800 mm, 1100 mm, 1400 mm, and 1700 mm) from the bottom of the column as shown in Fig. 1. These sampling tubes extended to the centre of the column's cross section. The sampling ports were closed by means of flexible tubing and a clip. CONMARK 314 stainless steel digital pocket thermometers were inserted at 170 mm and 1830 mm from the bottom of the column to monitor the column temperature. The column was mounted in a steel frame and a funnel and tubing arrangement provided on the frame at the same height as the top of the column for discharge of the column effluent.

The column was packed to a density of 1.55 g $cm^{-3}$ under saturated conditions with uniform silica sand of effective diameter of 0.51 mm and average diameter of 0.75 mm, obtained from WBB Minerals. The uniformity coefficient of the sand and porosity of the packing were found to be 1.6 and 0.41 respectively. Water saturated condition in the column was achieved by ensuring that the water level in the column was always above the surface of the sand during packing. After filling, the column was wrapped with aluminium foil to shut out light and discourage the growth of algae during operation. A variable speed peristaltic pump was used to deliver wastewater to the column through soft tygon tubing and a flow meter, which was fully opened and used for monitoring of flow to the column. An injection port consisting of a T-shaped glass tube with a septum stopper was provided in the influent line at the column entry for injection of a tracer during residence time studies.

### 2.2. *Column start-up and general operation*

The sand column was set up in a controlled temperature room set at 20 °C ± 0.5 °C. Synthetic wastewater was prepared by dilution in tap water of a stock solution containing 9.6 g