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Soil Aquifer Treatment for Additional Upgrading Wastewater Effluent

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Abstract

Soil Aquifer Treatment (SAT) systemscan be used for upgrading partially treated wastewater by allowing it to infiltrate into the soil for tertiary treatment and storage of water to meet the growing demand of wastewater reuse. In this study, a pilot plant of three soil columns of 2 m hight and 25 cm diametrwere designed and fabricated to study the quality improvement of the conventional effluent treated wastewater using three types of soil (fine, medium and coarse sand). The pilot was operated under three operational phases, The first phase was worked as 4 days wetting followed by 3 days drying cycle for a period of 6 months, the second phase was worked as 3 days wetting followed by 4 days drying for a period of two months. Meanwhile the third phase worked as 5 days wetting and 2 days drying for two months. The pilot plant of columns was feeding using the effluent of Qahasecondary wastewater treatment plant.

The results indicated that, the medium sandy soil operating with 3 days wetting/4 days drying cycles had the highest removal performance for BOD, COD and TSS (64%, 38 % and 86%) respectively. Fine, medium and Coarse soils can be operated under both 3 days wetting/4 days drying cycles and 5 days wetting/2 days drying cycles to meet the nitrification requirements of SAT under the Egyptian conditions.

تحسين نوعية المياه الخارجة من محطات الصرف الصحي عن طريق المعالجة الاضافية داخل التربة

ملخص

تساعد المعالجة داخل التربة على تحسين نوعية مياه الصرف الصحي المعالجة جزئيا وذلك عن طريق الترشيح داخل طبقات التربة التي تعمل كمعالجة ثلاثية لمياه الصرف الصحي وتخزن المياه بها لتلبية الاحتياجات المتزايدة للمياه باعادة استخدام مياه الصرف الصحي.
في هذه الدراسة تم تصميم وتصنيع نموذج من ثلاث أعمدة بارتفاع ٢م وقطر ٢٥ سم مملوؤة بأنواع مختفة من الرمال الناعمة والمتوسطة والخشنة لدراسة تحسين نوعية مياه الصرف الصحي الخارجة من معالجة تقليدية.
وهذا النموذج تم تجربته على ثلاث حالات تشغيل مختلفة: الأولى لمدة ٦ شهور بالغمر لمدة ٤ ايام ثم الراحة لمدة ٣ ايام بالتتابع، الثانية لمدة شهرينبالغمر لمدة ٣ ايام والراحة لمدة ٤ ايام، الثالثة لمدة شهرينبالغمر لمدة ٥ ايام والراحة لمدة ٢ يوم. وقد تم استخدام المياه الخارجة من محطة الصرف الصحي بقها لتجربة هذا النموذج. وقد دلت النتائج بأن التربة ذات الرمال المتوسطة الحجم في حالة التشغيل الثانية (٣ أيام غمر و ٤ ايام راحة) تعطي أعلى كفائة لازالة ملوثات الـ BOD،COD، TSS بنسب ٦٤% ٣٨% ، ٨٦% على الترتيب. بينما حالتي التشغيل الثانية والثالثة ومع الانواع الثلاثة المختلفة من التربة أدت الى ازالة المواد النيتروجينية تحت الظروف السائدة بمصر

Keywords: Soil Aquifer Treatment (SAT); Soil aquifer, Tertiary Treatment, Sewage Treatment.

Introduction

The growing competition for water around the world are leading to even greater use of the enormous water resource. As part of this trend, there has been increasable interest in the use of treated wastewater as a water resource, especially in the countries water-short resources. Stated simply, Soil Aquifer Treatment (SAT) is a process by which excess surface water is directed into the ground (either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration) to replenish an aquifer.

The impaired SAT waters quality is one of many strategies that can be used, alone or in conjunction with other strategies, to increase water supplies, such as reducing water consumption, reuse of treated wastewater or creating secondary water systems that deliver certain wastewaters directly to nonpotable uses. Aquifer recharge for the wastewater reuse has been considered and studied as a promising process to cope with the worldwide water scarcity [Elsheik&Elhamidy 2012, 21014].

SAT reclaimed water provides one of the possibilities of a supplement of groundwater with additional advantages as follows: reduction of groundwater levels decline, protection of underground freshwater in coastal aquifers against intrusion from the ocean, and storage of reclaimed water for future reuse [Miller 2006].

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,Essandoh et al. 2006].
The soil aquifer treatment technology may be an effective tool can be applied in Egypt for improving the quality of treated effluent sewage for the safety and non-restricted irrigation use compared with the direct currently common use. Through the aquifer soil, advanced sewage treatment stage was been added by which most of the biological load will be removed and reduction in concentrations of some chemicals can be found.

Materials and methods

Soil Aquifer Treatment Simulation

These experiments were performed using a pilot plant consisting of three parallel columns reactors, each column were constructed with a plastic tube (inner diameter of 25 cm and wall thickness of 0.5 cm). Column was equipped with 8 ports at equal heights (25 cm), 1 constant head overflow weir were located at depths of 25 cm from the top of the columns and used to maintain the desired constant head at the top of the soil, and 1 column outlet at the bottom. Sampling ports were installed at depths of 50, 100 and 150 cm from the top of the Soil and used for the collection of water samples, About 20 cm of headspace above the top soil was provided to pond the wastewater effluent during the flooding. Gravel support is at the bottom of the columnof 10 cm depth as shown in “Figure 1”.

Each column was filled with a kind of sand soil (coarse, medium, fine). Table 1 summarizes the characteristics of the columns soil. The columns were used to simulate a SAT system by employing three phases of cyclic operations.

Table 1. Characteristics of the column soils

Variables	Column A	Column B	Column C
Soil classification	Coarse Sand	Medium Sand	Fine Sand
Dry bulk density (g/cm^3)	1.54	1.56	1.53
Effective Size (mm)	0.425	0.3	0.25
Coefficient of Uniformity	3.6	2.5	6

Wastewater effluent and characteristics

Wastewater effluents were collected from QAHA wastewater treatment plant, El-Qulibya, Egypt. It receives sewage from Qaha city and it’s located at Qaha - Elqanater Road. Thus the secondary effluent from the plant, where wastewater is treated by an oxidation ditch process, was used in this study as a feed for the SAT-simulated soil columns. The quality of the influent and the effluent of the Qaha Wastewater Treatment Plant during the study period is summarized in Table 2.

Pilot Operation

The pilot plantwas started work from December 2013 till September 2014 (Ten Months) to cover the yearly climate change according to Egyption conditions and operated under three operational schedules: Phase 1 of 4 days wetting followed by 3 days drying cycle for a period of 6 months, Phase 2 of 3 days wetting followed by 4 days drying for a period of 2 months and Phase 3 of 5 days wetting and 2 days drying for 2 months using the secondary treated wastewater produced from QAHA treatment plant. The flow rate of wastewater that flow into the media was measured. The influent sample were obtained from the tank and analyzed at the same time of day to avoid change in the characteristics of the wastewater. Nine other samples (three samples for each column) at 1.5, 1 and 0.5 m soil depth were taken from the effluentthe three columns (after wetting days) then the system was turned to the drying cicledays .This procedure was repeated for the ten months.

Table 2.The quality of the influent and the effluent of the Qaha Wastewater Treatment Plant during year 2014

Parameter	Unit	Influent				Effluent			
		Av	Min	Max	S.D	Av	Min	Max	S.D
TSS	mg/l	230	213	312	13	17	8	43	2.84
VSS	mg/l	166	151	245	8.93	14	7	37	1.40
TDS	mg/l	774	723	795	31	692	666	726	23.8
BOD	mg/l	524	460	550	36	18	10	42	8
COD	mg/l	777	725	805	33	49	22	77	7
Oil& Grease	mg/l	29	23	41	7.15	3	1	5	1.67
PH	value	7.17	6.93	7.56	0.22	7.41	7.23	7.62	0.11
Temp	ºC	26	20	30	1.61	27	21	31	1.46

Analytical Measurements

The samples of wastewater and their charachteristics are chemically and physically analyzed in different laboratories. Biochemical oxygen demand (BOD), chemical oxygen demand (COD), total Suspended Solid TSS, PH and Temperature were analyzed in thelaboratory of QAHA treatment plant. While Ammonia NH3, nitrate NO3 and Phosphate P were analyzed in the Sanitary Engineering Lab in Benha faculty of Engineering, Benha and National Research Center, Cairo, Egypt. All the above mentioned parameters were analyzed according to the standard methods for examination water and wastewater 22nd edition 2005.

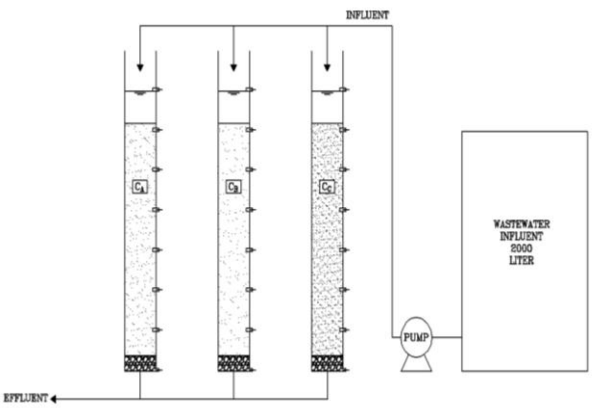

Figure 1. A schematic diagram of the SAT pilot plant system set-up used in this study.

Percent removal efficiencies of the measured parameters were calculated from

Re% = (1-C/Co) X 100 (1)

Where Re is percent removal efficiency (%), C is effluent concentration (mg/l), and Co is influent concentration (mg/l).

Results and discussion

BODand COD Removal

Wastewater contains a variety of natural and synthetic organic compounds, usually not individually identified, but collectively expressed in terms of the biochemical oxygen demand (BOD_5), and the chemical oxygen demand (COD. The soil with its biomass is extremely versatile and effective in decomposing natural and synthetic organic compounds that enter the soil with the wastewater. This decomposition tends to proceed more rapidly and completely under aerobic than anaerobic conditions. The fate of organic compounds in soil is normally not evaluated for each compound, but for the organic compounds collectively, as expressed by BOD_5 and COD.

Figure 2 shows the average BOD removal through the fine, medium and coarse sandy soil at differentoperation. The influent BOD ranged between 42 and 10 mg/L and. The influent wastewater quality refers to quality of Qaha wastewater plant. The result indicated that, the medium sandy soil is the most affected soil with maximum removal efficiency (Re%= 64 %) is obtained at Phase II operation cycle (3 days wetting / 4 days drying) at a flow rate 0.158 L/min.

The study of A.Akber, et al (2003) indicate that the BOD removal efficiency was 90% when using Muddy Sand and Gravelly Muddy sand. Madhavi, et al (2012) find that the clay is suitable for removing BOD & COD under frequent wetting and drying cycles.

Figures 3 shows COD removal during different operation cycles. The influent COD varied between 77 and 22mg/l, whereas the average value effluent varied between 29 and 19mg/l, for all types of soils , COD removal is not as good as BOD. This might be due to the presence of refractory organics in wastewater.

Medium sand soil is considered the most affected soil for removing COD in the phase 2 by efficiency 38%.

The study of A.Akber, et al (2003) indicate that the COD removal efficiency was 99% when using Muddy Sand and Gravelly Muddy sand. During SAT, the saturated (wet cycle) and unsaturated (dry cycle)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 leading to an improvement in water quality [Fox &Makam, 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 &Cotruvo. 2004,Dillon, et al. 2006]. Redox conditions and residence time can have a significant influence on the kinetics of dissolved organic carbon (DOC) degradation and may affect its removal efficiency[Grunheid, et al. 2005].

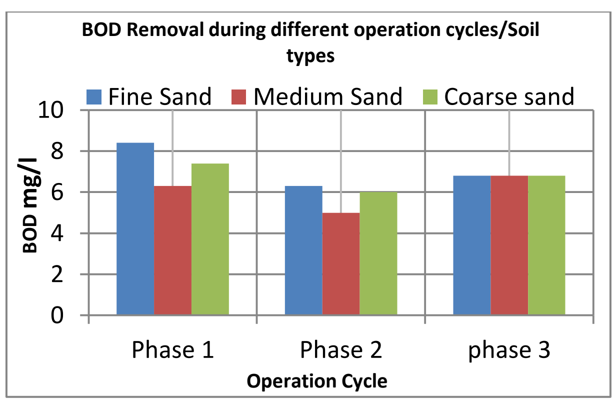

Figure 2. BOD Removal during different operation cycles/Soil types

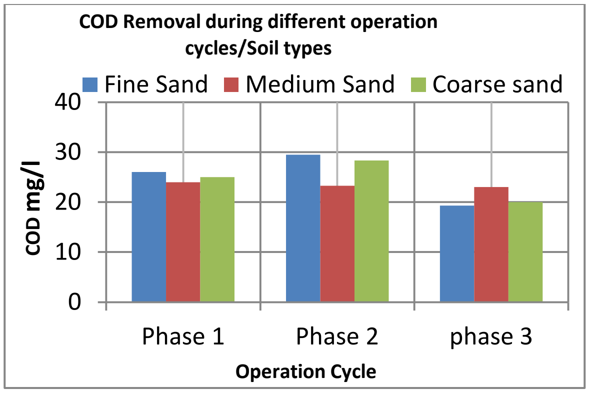

Figure 3.COD Removal during different operation cycles/Soil types

TSS Removal

Total suspended solids (TSS) are usually rather fine and mainly in organic form (sewage sludge, bacteria, fibrous materials, algae cells, etc.). The soil, however, is a very effective filter, and suspended solids should be essentially completely removed from the wastewater after about 1 m of percolation (M. Al-Senaft, et. Al 2005). The TSS at the inlet varied between 43 and 8mg/l. After the application of SAT, the TSS dropped to 1 mg/l in the three phases. The Highest Re% of TSS was obtained in the case of the medium sandy soil with value 86% at phase 2 operation cycle.Reductions of microbial in infiltrate wastewater were demonstrated using survival experiments. The reductions in microbial pathogens were attributed to a combination of physical removal processes and the activity of indigenous microorganisms [Toze&Bekele 2009].

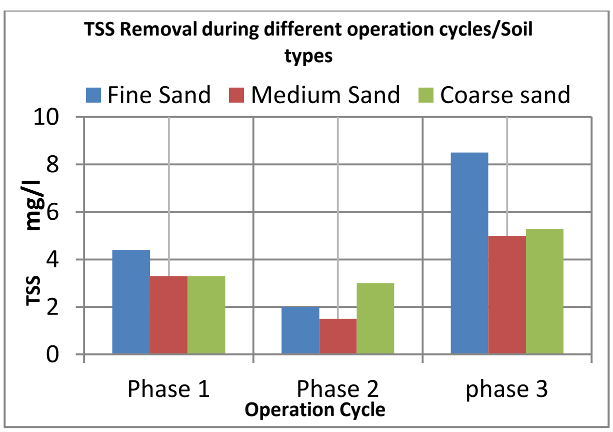

Figure 4. TSS Removal during different operation cycles/Soil types

A major operational feature of infiltration systems for treatedwatsewater is soil clogging caused by accumulation of suspended solids and strained out on the soil surface. The suspended solids can be inorganic, organic or grown biofilms. Their thickness may range from 1 mm or less to 0.3 m or more [Bouwer, 2002]. On the other hand, the controlled soil clogging accompanied with bioprocesses improves water quality. Considering both positive and negative influence of pollutant removal, biological clogging in porous media must be depicted by examining a correlation between bacterial growth and hydraulic conductivity [Page et al. 2011].

Three different clogging mechanisms were suggested depending on the flow rate and substrate concentration: (1) clogging at a high flow rate can be accelerated and easily eliminated by high shear force, (2) clogging at a low flow rate of local biofilm growths can be sloughed, and (3) clogging in a solution with high substrate concentrations cannot be easily eliminated because of the growth of dense biofilms [Kim et al. 2010].

Ammonia & Nitrate Removal

The nitrogen removal processes in a biological filter mainly involves several ecological processes, including ammonification, aerobic ammonium oxidation, nitrite oxidation, anaerobic denitrification, heterotrophic nitrification, aerobic denitrification, anaerobic ammonium oxidation, biological nitrogen fixation, dissimulator nitrate reduction, and Achaea ammonium oxidation (Ji et al. 2013, Satoh &Rulin 2004). According to previous research, nitrification and denitrification are the main mechanisms that are responsible for eliminating nitrogen from sewage water (Dong & Sun 2007; Wang et al. 2010). Kopchynski et al. (1996) studied the effects of soil type and effluent pretreatment on soil aquifer treatment. In this study, ten 2.6 m columns were operated under different flooding and drying cycles. The results indicate that effluent pre-treatment has a complete removal of ammonia.

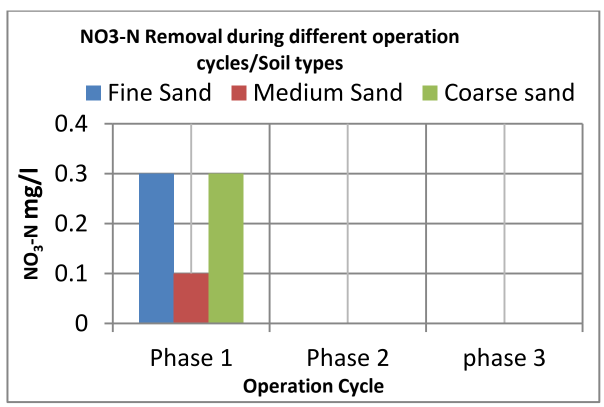

Figure 5. Nitrate Removal during different operation cycles/Soil types

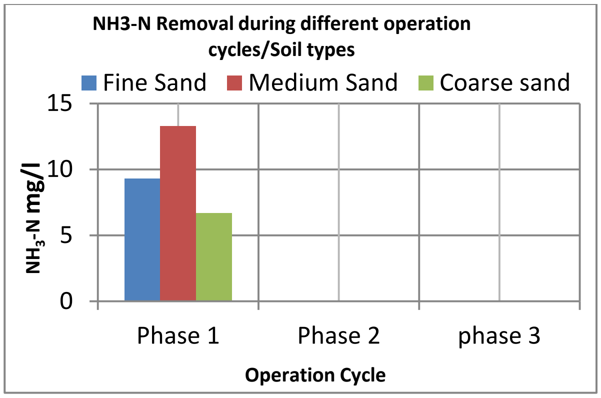

Figure 6. Ammonia Removal during different operation cycles/Soil types

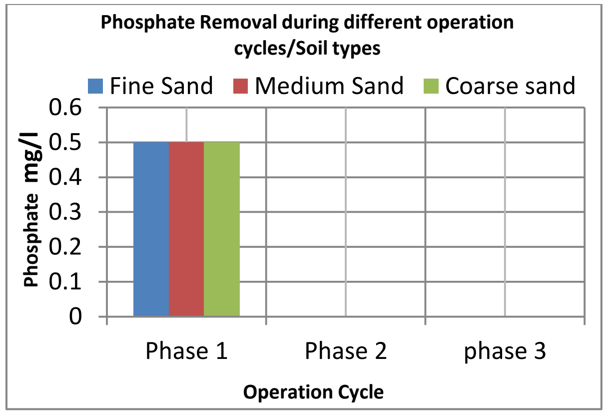

Figure 7. Phosphate Removal during different operation cycles/Soil types

In this experiment, For the first phase, the behavior of nitrate NO_3-N and Ammonia NH_3-N are decrease according to the stability of SAT system. Figure 5 shows the removal in Nitrate through soil column, its value was varied between 4.9 and 0.1 mg/l in the inlet for phase 1, 1.5 and 0.4 mg/l for phase 2 and varied between 1.6 to 0.2 mg/l for phase 3. The effluent of Nitrate is decrease to zero value in all soil columns at 1.5m soil depth.

Figure 6 shows the removal in ammonia through fine, medium and coarse sand soil. The level of ammonia in the inlet varied between 27.2 and 1.1 mg/l for phase 1, 25.7 and 13.5 mg/l for phase 2 and varied between 18.2 to 12.3 mg/l for phase 3. The effluent of ammonia is decrease to zero value in all soil columns, indicating the complete conversion of ammonia to nitrate. This indicates a high aerobic environment within the subsurface zone.

Highest Re% of ammonia and nitrate were obtained at Phase 2 operation cycle (3 days wetting / 4 days drying) for all types of soil with value 100%.

The unsaturated zone (during dry cycle) has available oxygen due to ability of air flow in its porous during the drying period of the SAT treatment cycle. Availability 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&Comakoglu 1996].

Phosphate Removal

The phosphate concentration within the effluent from Qaha wastewater treatment plant was 1.1 mg/l on average. It decreases in all soils at three phases till zero value. Its known that phosphate is removed either through its adsorption by phosphate-fixing materials, such as iron oxide and aluminum oxide, or through a precipitating reaction with the calcium and magnesium ions presented in soil (Bouwer2002). Therefore, the phosphate removal in this study indicates that the phosphate removal is depending on characteristics of the soil column.

Adsorption and precipitation are reported to be the main causes of phosphorous retention in calcareous sands and soils [Wandruszka, 2006].

Conclusion

Soil column studies were carried out to evaluate the potential of SAT system in treating wastewater under varied experimental condition viz. soil type, depth of soil, initial concentration of pollutants and pH. Based on the analysis of results the following conclusions have been drawn.

- The best removal efficiency occurs at 1.5 m soil.
- SAT system with medium sandy soil was more efficient in treating wastewater compared to fine and coarse sand.
- Medium sand is the better soil for reducing BOD, COD and TSS under phase II operation cycle (3wetting / 4drying).
- Soil column experiments showed that nitrification can remove up to 90 % of ammonium nitrogen within a column of 1.5 m depth and also denitrification can be achieved during soil passage.
- Phosphate removal was generally very high.

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