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Optimum soil depth for removal of coliphage viruses from treated wastewater, Kuwait

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ABSTRACT

A study was carried out to determine the optimum soil depth for the removal of coliphage viruses from treated wastewater. Treated wastewater containing viruses was passed through soil columns filled with soil collected from Sulaibiya area, Kuwait. The soil column experiments were under operation for eight months during the period from August 2004 to March 2005. Three soil depths were used in these experiments. These are 0.1, 0.2, 0.4, and 0.8 m of natural Sulaibiya soil. For each experimental condition, two identical columns were set up, so that the changes of the results can be evaluated, producing total of eight columns. For all columns, the coliphage tests were studied only under alternating 1 d flooding and 1 d drying conditions. Influent and effluent coliphage samples were collected and analyzed following cycles of flooding periods. The coliphage virus count in the treated wastewater ranged between 0 and 62,800 pfu/100 ml. The laboratory results revealed that coliphage removal for Sulaibiya soil ranged between 58 and 100% for soil depth of 10 cm, and the viruses were completely removed after passing 20 cm thickness of soil. Also, the results indicated that no virus breakthrough occurred at soil depths of 40 and 80 cm.

Keywords: Coliphage viruses; Treated wastewater; Soil column experiments; Effluent

1. Introduction

Kuwait is a modern industrialized nation that meets most of its domestic, commercial, and industrial water needs by desalination of seawater. However, while desalination technologies demonstrated a remarkable progress in recent years, they still do not present a viable economical option for wide agricultural use. Therefore, countries with limited water resources carry on research effort into agricultural use of wastewater since recycling of renovated wastewater generates a valuable water resource.

As Al-Otaibi [1] pointed out, Kuwait produces 135 million m^3 of tertiary treated wastewater per year, of which only 40% is used for irrigation, while the remainder is being discharged to the Arabian Gulf. The volume of tertiary treated wastewater is set to increase in line with growing population and escalating water needs. In this context, the methods that can restore the wastewater quality to usable levels will be gaining and ever increasing importance.

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Water for agriculture needs to meet stringent quality criteria, which include absence of pathogens like virus and bacteria, and low nitrogen levels [2]. These parameters are difficult to achieve within economic realms of existing purification technologies. Therefore, researchers concentrate on efficient ways of improving the quality of wastewater using natural environments; for example, soil.

Coliphage viruses (i.e. viruses that use *Escherichia coli* bacteria cells as host) were selected for this study because their structure, composition, morphology, and size closely resemble that of enteric viruses, they are easily grown on bacteria cultures, and only simple materials and equipments are needed for coliphage detection and quantification by plague forming units (pfu) [3]. Also, coliphage viruses are chlorine-resistant micro-organisms and considered as indicators for wastewater viruses.

Soil Aquifer Treatment (SAT) technique is an economically attractive method for the treatment of wastewater for restricted and unrestricted irrigation [4]. These systems are operated to use underground formations as a treatment facility, and thus are called SAT or geo-purification systems. While significant research effort has been applied to SAT throughout the world, there is an evident need to test this technique with local Kuwaiti soils, wastewater, and climatic conditions. A laboratory study concentrated on the tertiary treated wastewater from the Sulaibiya Wastewater Treatment Plant, treated by sandy soils from Kuwait.

Adsorption appears to be the predominant factor in virus removal by soil [5–8]. Thus, factors influencing adsorption phenomena will determine not only the efficiency of short-term virus retention but also the long-term behavior of viruses in the soil. Such factors include soil composition, salt deposition, micro-organisms, and the presence of soluble organic matter. Viruses are readily adsorbed to clays, and the higher the clay contents of the soil, the greater the expected removal of viruses [7]. Sandy loam soils and other soils containing organic matter are also favorable for virus removal. Soils with a low surface area do not achieve good virus removal [9]. Soluble organic matter competes with viruses for adsorption sites on the soil particles, resulting in the decreased virus adsorption [10]. The objective of the study was to assess the removal of coliphage viruses from treated wastewater by the SAT system in Kuwait.

2. Methodology

2.1. Soil collection and properties

One type of soil that was used in column experiments includes soil collected from Sulaibiya area, Kuwait. Soil samples from the top 10 cm from the Sulaibiya area were used to fill eight soil columns. Each 5 cm of soil inside the column was compacted until filled the required total soil length and this compaction method will produce density (1.8 g/cm^3), specific gravity (SG) (2.63) similar to their values in the field. The soil samples collected from Sulaibiya area were tested to determine the properties of the soil. These properties included grain size distribution, specific surface area (SSA), total organic carbon content (TOC%), total carbonate content (CO_3%), cation exchange capacity (CEC), density, SG, porosity (P), and fine materials (silt and clay) content of the soil. These soil properties were analyzed using standard soil methods described by Page et al. [11].

2.2. Design and column construction

Total of eight soil columns were constructed to study the removal of viruses from tertiary treated wastewater using different soil depths. The columns for the tests of virus were constructed using polyvinyl chloride (PVC) pipes of 0.1 m in diameter. Columns with standard diameters of 0.1 m were practical for water sampling in the laboratory, easy to fabricate, cheap and used in other researches [12–15] in the field of SAT system, and allowed to correlations of the results of this study with the work of the pervious researches under the similar laboratory conditions. The PVC pipes were selected to reduce contamination and interaction between Coliphage and the column walls. The total length contained 0.05 m of gravel, 0.1–0.8 m of natural soil, 0.1 m of constant wastewater head, and a margin of safety (Fig. 1). The depth of the natural soil was selected as the optimum depth for virus removal, following the practices of previous researchers [16–18]. The gravel in this study was used as a filter zone to prevent the passing of fine materials through the outlet. The column numbers one and two, three and four, five and six, and seven and eight were filled with 0.1, 0.2, 0.4, and 0.8 m of natural soil, respectively.

2.3. Column operation and maintenance

The tertiary wastewater was pumped daily from the Sulaibiya Data Monitoring Center to a high level 1893 l tank through a PVC line. The tertiary treated wastewater was fed to all the soil columns simultaneously. The tertiary treated wastewater header tank and all the feeding PVC lines were flushed regularly during maintenance periods of column operation. The soil columns were recharged with treated wastewater during the period from August 2004 to February 2005.

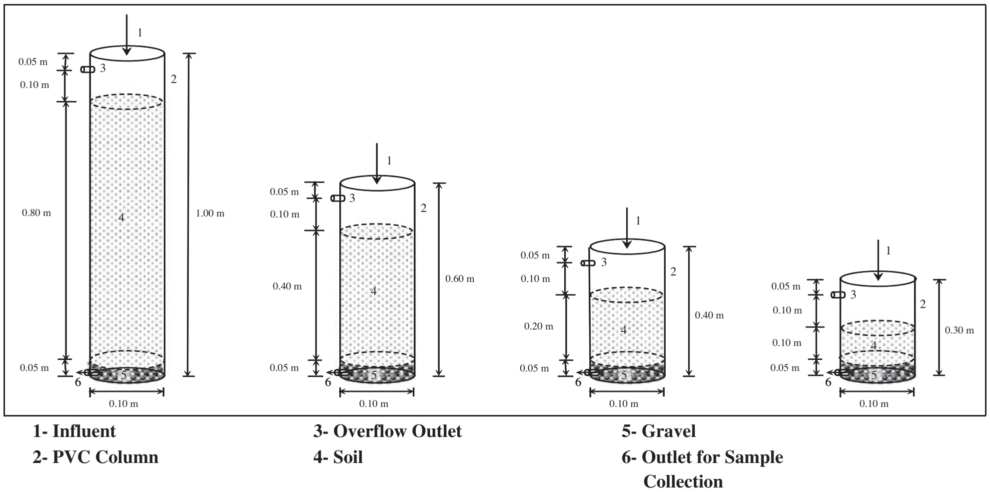

Fig. 1. Design of soil column experiments.

During the period from August 2004 to 20 November 2004, tertiary treated wastewater was used for recharge. After this period, there was a change in the quality of water used for recharge due to the mixing of tertiary treated wastewater from Al-Jahra wastewater plant with reverse osmosis (RO)-treated wastewater from Sulaibiya Plant Utility Company at Sulaibiya area. On 14 February 2005, only the RO-treated wastewater was passing through the soil columns.

Constant heads of wastewater was used in measuring the removal of coliphages from the wastewater, i.e. 0.1 m. These constant heads were maintained for the soil columns by overflow outlets above the soil surface. For each experimental condition, two identical columns were set up, so that the variability of the results can be assessed. The coliphage tests were studied only under alternating flooding and drying conditions. All columns were subjected to short flooding and drying cycles of 1 d of flooding alternating with 1 d of drying for eight months. During the drying periods and at the end of each month, the maintenance of the soil columns was carried out by scratching organic layer on top of soil surface using long plastic forks and removing this layer to increase the infiltration rate. The infiltration rate was measured for columns at the beginning of the flooding period, and calculated according to the following equation [18]:

$$\text{Infiltration rate } (I) = V/At \qquad (1)$$

where V is the volume of the outflow in time t and A is the cross-sectional area of the soil column. In this study, infiltration rate was expressed in m/d.

2.4. Wastewater sampling and analysis

Samples of effluent were collected 24 h after the flooding periods. Each sample was separated into two subsamples, and measurements of the coliphage content of each subsample were carried out to ensure the accuracy of the analyses. Influent and effluent coliphage samples were collected following cycles of flooding periods. Samples were collected using sterile 100 ml glass bottles with glass stoppers, and they were analyzed within 4 h of collection. Any samples kept for 4–24 h were cooled to at least 10°C. Virus samples were analyzed by laboratory of Water Research Center laboratory at KISR using the standard methods for the examination of water and wastewater [3]. Fresh bacteria and coliphage media were prepared at the end of each month. Modified Tryptic Soy Agar media and *E. coli* C (host culture, WARD'S No.85W1662) were used for detection of coliphage viruses [3].

3. Results and discussion

The result of grain size distribution for Sulaibiya soil is plotted in Fig. 2. The S-shaped grain size graph indicates rather poorly sorted distributions spanning the gravel, sand, and fine classes. The soil tested consisted of sandy soils with different percentages of fines (i.e. silt and clay). Al-Haddad [19] reported that Sulaibiya soil consists of 97.5% sand, 1.5% silt, and 1% clay. The mean value of fines for tested soil samples was found to be 2.5%. The amount of fines was found to be an important factor for the removal of virus by adsorption within the soil particles. The mean values

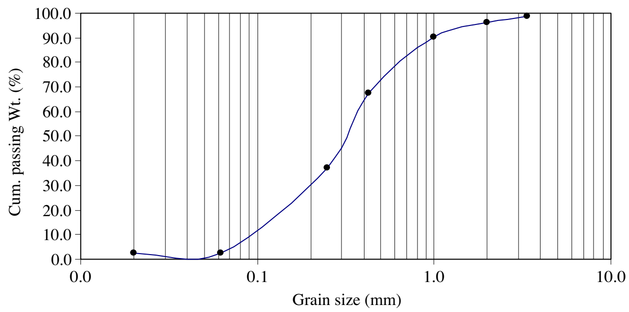

Fig. 2. Grain size distribution for Sulaibiya soil.

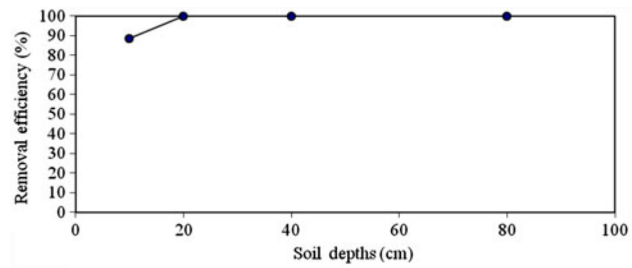

Fig. 4. Results of coliphage removal efficiency for different depths of Sulaibiya soil.

of porosity, SSA, CEC, total organic carbon, and carbonate percentage were found to be 33%, 8.22 m^2/g, 2.43 meq/100 g, 343.23 mg/kg, and 5%, respectively. Soils with high contents of fines, organics, and carbonates are expected to adsorb more viruses from treated wastewater.

The coliphage viruse counts in the treated wastewater ranged between 0 and 62,800 pfu/100 ml during the studied period. However, the coliphage counts decreased when the tertiary treated wastewater was mixed with RO-treated wastewater, and finally the coliphage counts were absent in the RO-treated wastewater at the end of soil column experiments.

The results of different depths of soil on coliphage virus removal from the treated wastewater are presented in Figs. 3 and 4. The laboratory results revealed that coliphage removal ranged between 58 and 100% with average value of 88.4% for soil depth of 10 cm, and the viruses were completely removed after passing through 20 cm thickness of soil. Also, the results indicated the absence of coliphage viruses in the outlet samples after passing through soil depths of 40 and 80 cm. It is clear from Fig. 3 that the soil composition (2.5% fines and 343.23 mg/kg as TOC) is an

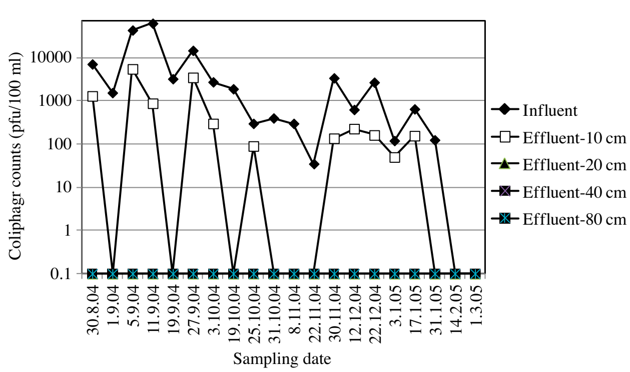

Fig. 3. Coliphage counts in influent and effluent samples after passing different soil depths.

important factor in removing viruses from tertiary treated wastewater. A similar soil column experiment was carried out by Lance et al. [15] to study the adsorption and movement of viruses and to determine whether the calcareous sandy soil could be saturated with viruses found in secondary wastewater. Secondary wastewater containing 30,000 pfu of virus per milliliter was passed through 250 cm of soil. Viruses were not detected in samples extracted from the columns below 160 cm. They reported that viruses were mostly adsorbed at the top 5 cm of soil which contained less than 5% fines (silt and clay). The present study also confirmed these findings. The low fine material contents (silt and clay materials), organics, and carbonates in the Sulaibiya soil was enough to adsorb viruses to these soil particles. The infiltration rates were measured only for 10 cm soil columns; their values ranged between 0.8 and 10.9 m/d. In general, the infiltration rated at the early stages were high and then decreased with time.

4. Summary and conclusions

Soil column experiments were carried out to determine the removal of coliphage viruses from the tertiary treated wastewater using the SAT. Different soil depths (0.1, 20, 40, and 80) were used in the laboratory experiments for this purpose. Total of eight soil columns were constructed at the KISR wastewater research building in the Sulaibiya area. Soil samples were collected to fill the columns and to determine their properties. The treated wastewater was pumped daily from the tank and fed to all the soil columns. All columns were subjected to short flooding and drying cycles of 1 d of flooding alternating with 1 d of drying for eight months. Samples of influent and effluent water were collected 24 h after the flooding periods.

High coliphage viruses were found in the tertiary treated wastewater (62,800 pfu/100 ml) and their counts was reduced after mixing it with RO-treated wastewater. The laboratory results revealed that coliphage removal for Sulaibiya soil ranged between 58 and 100% for soil depth of 10 cm, and the viruses were completely removed after passing through 20 cm thickness of soil. Moreover, no virus breakthrough occurred at soil depths of 40 and 80 cm. The content of fines, organics, and carbonates in the Sulaibiya soil was sufficient to remove all the viruses from the treated wastewater. Based on the laboratory experiments, following recommendations are forwarded:

(1) The removal efficiency of bacteria and viruses (enteric viruses) from the wastewater using the SAT system should be determined in the field. The field study should be conducted over a period of several years and conclude with a detailed presentation of all expected benefits and disbenefits of SAT in technical, environmental, social, economical, and related terms. This study should also provide a set of detailed guidelines on use of SAT in Kuwait.
(2) The operation of SAT system should be applied separately for both the RO-treated wastewater mixed with tertiary treated wastewater and/or tertiary treated wastewater to compare the bacteria and virus removal efficiency from the both types of water.
(3) In agricultural areas, the RO-treated mixed with tertiary treated wastewater and/or tertiary treated wastewater should be passed through the soil similar in content to the Sulaibiya soil before this water is used for irrigating the crop fields. In the case of not finding the similar natural soil, the available soil can be modified by the addition of 2.5% fines (silt and clay) to it.

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