Removal of Antibacterial Agents by Advanced Membrane Technology and ODTMA-Micelle-Clay Comlex.

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Abstract: The efficiency of sequential advanced membrane technology wastewater treatment plant towards removal of amoxicillin and cefuroxime axetil from wastewater was investigated. The sequential system included activated sludge, ultrafiltration (hollow fiber membranes with 100 kDa cutoff, and spiral wound membranes with 20 kDa cutoff), activated carbon column and reverse osmosis (RO). The overall performance of the integrated plant showed complete removal of amoxicillin and cefuroxime axetil from spiked wastewater samples. The adsorption isotherms for these compounds have been studied using both activated carbon adsorbent and newly developed adsorbent named micelle-clay complex (octadecyltrimethylammonium (ODTMA)–clay (montmorillonite)). The results revealed that both isotherms adsorption fit the Langmuir equation with Q_{max} of 100 mg/g and 90.91 mg/g, and with K values 0.229 L/mg and 0.158 L/mg for amoxicillin using activated carbon and micelle-clay complex, respectively, and with Q_{max} of 26.31 mg/g and 31.25 mg/g and with K values 0.271 L/mg and 0.122 L/mg for cefuroxime axetil using activated charcoal and micelle-clay complex, respectively. Removal of amoxicillin and Cefuroxime axetil from polluted water in high concentrations (100 ppm) by column filter including a mixture of micelle-clay or activated charcoal composite with sand indicated an efficient removal of both pharmaceuticals.
Keywords: Antibiotics; Amoxicillin; Cefuroxime axetil; Wastewater; ultrafiltration; Activated carbon; Clay micelle complex; Adsorption.

1. Introduction

1.1. Background

In the Middle East, in general, and Palestine, in particular, water resources are very limited and currently a serious shortage problem exists [1-3].

This situation will be aggravated in the future since the water balance gap between the available water supplies and the water demand will increase as a result of population growth, rapid urbanization and industrialization associated with living standards improvement. This gap will cause serious shortage of fresh water to be used for human purposes, agricultural, and other non-human purposes, Hence, water contamination and the production of large volume of wastewater are the expected results [4-7].

The ground water is the main source of fresh water in Palestine. The sources of fresh water in Palestine suffer from Israeli confiscation and control [8]. Compared to groundwater, surface water is the insignificantly important in the West Bank. The only source of surface water in the area is the Jordan River; Palestinian access to fresh surface water from the Jordan River is almost zero because of Israel's control of the flow of the river [9].

This situation requires us to preserve all water supplies that currently exist, control water usage and use it efficiently, and minimize water pollution and water contamination by reducing wastewater flows and also finding solutions for the disposal, treatment and recycling of wastewater.

Due to water shortage, the treatment of wastewater has become of increasing interest, in order to protect water sources and supplement the available amount of water for irrigation. The level of treatment is still a controversial issue. Quite a few countries are moving rapidly towards advanced treatment by which wastewater approaches fresh water quality [10].

Wastewater is one of the major sources of pollution that has serious hostile impact both on the environment and local residents. The wastewater sector status in Palestine is characterized by poor sanitation, different quality, insufficient treatment, and unsafe disposal of untreated or partially treated wastewater into the environment. Sewage collection networks in the West Bank are limited to major cities and to certain portions of these municipalities. Most of them are poorly designed and old [5,11]. Therefore, the situation of the sewerage system is extremely critical [12, 13].

The efficient sewage treatment systems are urgently needed in Palestine, because an appropriate and a sustainable sewage treatment technology will help to preserve biodiversity and maintain healthy ecosystems [5].

In Palestine two types of treatment plant systems are used conventional and less conventional: stabilization ponds for small communities, trickling filter, oxidation ditches, and activated sludge for large scale community [5].

1.2. Wastewater: Definition and Characteristics

The more specific definition of wastewater is a combination of water carried wastes removed from residence, institution, commercial, industrial establishments, and ground water [14, 15]. Wastewater is about 99% water by weight referred as influent, and the remaining one percent includes suspending and dissolved organic substances, as well as microorganisms [16]. But this ratio may vary according to the activity that wastewater resulted from, but the constituent's ratio is not less than 95% [15-19].

Wastewater is characterized in terms of its physical, chemical, and biological composition [20] Physical parameters include total solid contents, particle size distribution, turbidity, temperature, conductivity, transmittance, density, color, and odor. Total solid contents

are subdivided into total suspended solids (TSS) and total dissolved solids (TDS). Chemical parameters associated with the organic content of wastewater include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total oxygen demand (TOD).

Inorganic chemical parameters include salinity, hardness, pH, acidity and alkalinity, as well as concentrations of ionized metals such as iron and manganese, and anionic entities such as chlorides, sulfates, sulfides, nitrates, and phosphates. Bacteriological parameters include coliforms, fecal coliforms, specific pathogens, and viruses [14, 20].

1.3. Overview of wastewater treatment

Wastewater treatment is the process of removing varying amounts of contaminants from wastewater, depending on the level and type of treatment they provide. Its objective is to optimize the benefits of wastewater as a resource of both water and nutrients, and to ensure protection of public health and the environment from the discharge of untreated or inadequately treated wastewater effluents [21].

Also, in wastewater reclamation and reuse, water quality requirements may call for reduction in suspended solids, total dissolved solids, pathogenic microorganism (i.e. bacteria, protozoan, and viruses), as well as selected constituents such as nitrates, chlorides, and natural and synthetic organic compounds [14].

1.4. Wastewater treatment plant process

Treatment facilities incorporate numerous processes, which in combination achieve the desired water quality objectives. These processes involve the separation, removal and disposal of pollutants present in the wastewater.

The treatment of wastewater is accomplished by four basic methods or techniques; physical, mechanical, biological and chemical. The physical method of treatment is unit operations used in wastewater treatment include; flow-metering, screening, mixing, sedimentation, accelerating gravity settling, floatation, filtration gas transfer and volatilization.

Mechanical treatment methods involve the use of machines. Chemical treatment methods include many processes such as chemical precipitation, adsorption, disinfection, and dechlorination. The biological method plays a vital role in the removal of pollutants which cannot be effectively achieved by other means [22, 19].

Water treatment usually consists of four stages: preliminary, primary, secondary, and tertiary. But the primary and secondary stages are considered the major steps, and the tertiary stage is required to achieve complete removal for pollutants which have not been removed by secondary treatment [16].

1.4.1. Preliminary treatment

The influent that flows to treatment plant contains pieces of wood, rags, plastic and other debris in addition to sand, eggshells and other coarse inorganic materials, as well as organic matter from household, industrial, commercial and institutional water use; all these components are removed through combination of screening and settling [14, 19, 23, and 24].

1.4.2. Primary treatment

In primary treatment, the objectives are to physically remove, large debris, grit and sands from wastewater by screening, settling, or floating [16].

During primary treatment wastewater flows into and through large settling tanks or clarifiers where the flow velocity is reduced. Here initial separation occurs, with 40% to 50% of the heavier settle able solids forming primary sludge on the bottom of the settling tanks, and lighter materials float to the tanks surface [19].

1.4.3. Secondary treatment

The secondary treatment is designed for removal of biodegradable dissolved and colloidal organics and suspended solids that have escaped the primary treatment by utilizing biological treatment process. In secondary treatment unit, three types of technologies can be applied to break down organic material with agitation and aeration. There are: activated sludge process, trickling filters, and lagoon system [14, 23].

Activated sludge process removes the dissolved organic material and converts colloidal matter to a biological sludge which rapidly settles. The activated sludge process uses a variety of mechanisms to utilize dissolved oxygen to promote the growth of biological flock that substantially breaks down and removes organic material, then allows these solids flock to settle out [19, 24-25].

1.4.4. Tertiary treatment

Any addition processing after secondary treatment is called tertiary treatment which is physical-chemical processes applied to remove more suspended solids, organic matter, nitrogen, phosphorous, heavy metals and bacteria.

These processes include ozonation, photo-catalytic degradation of recalcitrant compounds (UV/TiO_2), and adsorption [20, 25-26].

Tertiary treatment may also involve physical-chemical separation techniques such as carbon adsorption, flocculation/precipitation, membranes for advanced filtration, ion exchange, dechlorination and reverse osmosis [27].

1.5. Membrane filtration

Membranes filtration are frequently used for tertiary treatment of wastewater before discharge to surface water, recover materials in industry before they enter waste streams, and to treat waters for potable use [28].

Application of membrane technology to wastewater treatment has expanded due to increasingly stringent legislation and continuing advancement of membrane technology [29].

Membrane filtration technology is a separation process, in which a semi-permeable membrane acts as a filter that allows water flow through, while removing suspended solids and other substances [30].

In membrane separation process, the feed water is separated into stream that can pass through the membrane known as permeate, and a fraction of feed that cannot pass through the membrane known as retentate or concentrate [31].

The removal of suspended or colloidal particles based on the size of membrane pores relative to that of the particulate matter, in the applications that require the removal of dissolved contaminants, the molecular weight cutoffs (MWCO) is considered the main criteria for effective

separation, because it specifies the maximum molecular weight of solute to be rejected, the removal process will be in range of 100 to 500 Daltons [30].

Other parameters such as the kind of driving force (pressure, chemical structure and composition of membrane, geometry of construction, and type of feed flow) play a vital role in the membrane filtration process [28].

1.5.1. Types of membranes

There are four main types of modules: plat, frame, tubular spiral wound, and hollow fiber [32].Hollow fiber and spiral wound modules constructions involves sealing the membrane material into an assembly, these types of modules are designed for long-term use (number of years), these modules are used in drinking water treatment and also wastewater treatment [14, 33].

Hollow fiber and spiral wound are made from organic material (synthetic polymers i.e. polyamide, polysulphone). Hollow fibers is a narrow tube made of non-cellulosic polymer, in this type a bundles of individual fibers are sealed into a hydraulically housing, the fibers usually have a small diameter, around 100 µID and ~ 200 µmod. In hollow fiber the feed flows into the module, the permeate flow into or out of the hollow fiber and is collected, while retentate exits the module for further treatment [34-35].

Spiral wound is one of the most compact and inexpensive membrane, in this type two flat sheet membranes are placed together with their active sides facing away from each other.

Each flat sheet membrane has one active side through which the smaller molecules permeate through, a feed spacer which is a mesh like material is placed between the two flat sheet membranes, and the two flat sheet membranes with feed spacer separating them are rolled around perforated tube which called collection tube.

Membrane filtration can basically be divided into four main technologies based on the driving force used for filtration: Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Hollow fiber and spiral wound are used for microfiltration (MF), ultrafiltration and also reverse osmosis (RO) [36].

The driving force can be external pressure, electrical potential gradient, concentration gradient, or other driving forces, the most commonly used membrane system in water and wastewater treatment are pressure-driven membrane. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) use the pressure-driven force and are classified according to their pore size [28, 37].

1.6. Occurrence of Pharmaceuticals and personal care products (PPCPs) in wastewater

The occurrence of pharmaceutically active substances and their metabolites and also personal care products (PPCPs) in the environment has become an important issue in the last few years.

These compounds along with their metabolites, which can be even more harmful than the original compounds, are continuously released in the environment, mainly through disposal of unused or expired drugs or directly from pharmaceutical discharges [37].

Thousands of tons of pharmaceuticals are used yearly with different purposes, such as prevention, diagnosis, care, and mitigation of diseases or improve the state of health, the same quantity or more consumed from PPCPs which include analgesics, fragrances, sun screen, shampoos and cosmetics [38].

Public awareness and concern has grown significantly over the past three decades and has brought this issue to the forefront in the water quality area [37].

Pharmaceuticals are generally excreted after being partially or completely converted to metabolites with enhanced solubility in water, but a significant quantity of the parent drug may also be excreted unchanged [39].

Most of these compounds come either from domestic sewage or from hospitals, or industrial discharges and enter municipal Wastewater Treatment Plants (WWTPs). Their removal efficiencies are influenced by the chemical properties of specific compounds, by microbial activity and environmental conditions [40-42].

Recent studies have clearly shown that the elimination of pharmaceutically active compounds (PhACs) in municipal WWTPs is often incomplete [43].With efficiencies ranging between 60% and 90% for a variety of polar compounds [44-45].

A major factor influencing the efficiency of pollutants removal from water is their ability to interact with solid particles, both natural (clay, sediments) or added to the medium (active carbon, coagulants) and with microorganisms, because this facilitates their removal by physical–chemical (settling, flotation) or biological processes (biodegradation). However, compounds with low adsorption coefficients tend to remain in the aqueous phase, which favors their mobility through the WWTP into the receiving environment [46].

1.6.1. Analytical methods

The presence of pharmaceuticals at trace levels (ngL^{-1}) in complex water matrices, such as wastewater and surface water poses a major difficulty for their analysis [47].

Currently, no standardized analytical methods are available for the analysis of pharmaceuticals and organic micropollutants in the environmental waters [48].The most common sample isolation and pre-concentration technique is solid phase extraction (SPE) [49].SPE also used for cleanup of pharmaceuticals in water samples [50].Variations of SPE include solid phase micro-extraction (SPME) and various on-line and automated SPE techniques [51].

1.6.2. Antibiotic pharmaceuticals in wastewater

Antibiotics are a class of naturally-occurring, semi-synthetic and/or chemically synthetic compounds with antimicrobial activity. They are widely used in human and veterinary medicine to treat and prevent diseases [51-52].

The presence of antibiotics in the aquatic environment has created two concerns. The immediate concern is the potential toxicity of these compounds to aquatic organisms and humans through drinking water. In addition, there is growing concern that a release of antibiotics to the environment might contribute to the emergence of strains of disease-causing bacteria that are resistant to high doses of these drugs [53-54].

Antibiotics as an important group of PhACs have been first produced in early 1940s and widely used in fighting against infectious bacteria and fungi [55].

Researchers have shown that several classes of antibiotics and PPCPs are present in domestic effluents and aquatic environments [56-57].Since they are often not fully assimilated

by humans and animals during treatment [58, 59].In addition, most of them show a recalcitrant behavior and are not easily removed from wastewaters in sewage treatment plants (STPs) [60].

The types and concentrations of antibiotics in the environment vary among areas and countries, depending on antibiotic consumption and use patterns [57]. In some industrialized countries, WWTP effluents containing antibiotics used in human medicine are the major sources of antibiotics in the aquatic environment [61]

Antibiotic occurrence in aquatic systems is also affected by their chemical stability and partition characteristics [62].For example, sulfonamides exhibit high solubility and chemical stability in water, whereas macrolides tend to be hydrolyzed or sorbed to soil and sediments [63].

Quinolones are susceptible to photodegradation [64], and are also adsorbed in sediments [65].And tetracyclines have a high affinity for soil organic matter through cation bridging and cation exchange [66].

In recent years, the incidence of antibiotic resistant bacteria has increased and many people believe that the increase is due to the use of antibiotics. Furthermore, the presence of antibiotics in wastewaters has increased in recent years and their abatement will be a challenge in the near future [67-70].

1.6.3. Method of treatment

Albeit pharmaceuticals residue and their metabolites are usually detectable in the environment at trace levels, the low concentration level (ngL^{-1} - μgL^{-1}) can induce toxic effects, as in the cases of antibiotic and steroids that cause resistance in natural bacterial populations or endocrine disruption effects [71].

Generally the methods used for wastewater treatment are biodegradation, deconjugation, partitioning, and removal during sludge treatment and photodegradation [72-73].

As a consequence, removal of pharmaceutical substance before entering the aquatic environment as well as for water reuse is very important. Furthermore, to ensure compliance with future discharge requirements, upgrading of existing water and wastewater treatment plants and implementation of new technologies are considered as the next steps in improvement of wastewater treatment [74].

This study reports the efficiency of Al-Quds Wastewater Treatment Plant for the removal of two antibacterials, amoxicillin and cefuroxime axetil. Al-Quds University wastewater treatment plant includes ultrafiltration membranes such as hollow fiber and spiral wound, and reverse osmosis. In addition, the adsorption results of these two antibacterials onto activated carbon and ODTMA-clay-micelles complex is reported.

It is worth noting that the micelle–clay composites that were used in this study are positively charged, have a large surface area and include large hydrophobic domains. It was shown by X-ray diffraction, electron microscopy and adsorption experiments that the characteristics of the micelle–clay complexes are different from those of organo–clay complexes which are formed by adsorption of the same organic ODTMA (octadecyltrimethylammonium) cation as monomers [75].

1. Experimental

2.1. Instrumentation

2.1.1. High Performance Liquid Chromatography

High Pressure Liquid Chromatography (HPLC-PDA) system consists of an alliance 2695 HPLC from (Waters: Israel), and a waters Micromass® Masslynx ™ detector with Photo diode array (PDA) (Waters 2996: Israel). Data acquisition and control were carried out using Empower ™ software (Waters: Israel). Analytes were separated on a 4.6 mm x150 mm C18 XBridge ® column (5 µm particle size) used in conjunction with a 4.6mmx20 µm XBridge ™ C18 guard column. Microfilter was used with 0.45µm (Acrodisc® GHP, Waters).

2.1.2. UV-Spectrophotometer

The concentrations of the drugs in samples were determined spectrophotometrically (UV-spectrophotometer, Model: UV-1601, Shimadzu, Japan) by monitoring the absorbance at λmax for each drug.

2.1.3. pH meter

pH values were recorded on pH meter (model HM-30G: TOA electronics ™).

2.1.4. Centrifuge and Shaker

Labofuge®200 Centrifuge was used (230 V 50/60 Hz. CAT. No. 284811, made in Germany). Some of pharmaceuticals solutions were shaken with an electronic shaker (Bigbill shaker, Model No.: M49120-26, 220-240 V 50\60 Hz.) at 250 rpm.

2.2. Description of Wastewater Treatment Plant (WWTP)

The wastewater treatment plant (WWTP) at Al-Quds University collects a mixture of black, gray, and storm water. The treatment plant consists of a primary treatment (two stage primary settling basin), and a secondary treatment (activated sludge with a hydraulic retention time of 16-20 hours, coagulation and chlorination).

Then, the secondary effluent is introduced to the sand filter before entering the ultra-filtration membrane (Hollow fiber and Spiral wound). After the ultra-filtration process, the effluent is subjected to activated carbon column followed by a reverse osmosis (advanced treatment).

Then, a blend of all effluents is used for irrigation. The ultra-filtration process is made of two small scale membrane treatment plants with a capacity of 12 m^3 /day. The first UF unit is equipped with 2 x 4 inch pressure vessels with pressure resistance up to 150 psi. Each vessel holds two separation membranes (spiral wound with 20 kD cutoffs which is equivalent to 0.01 micron separation rate).

The designed permeate capacity of the system is 0.5-0.8 m^3/h. This Membrane can remove bacteria, suspended solids, turbidity agents, oil, and emulsions. The second unit is equipped with two pressure vessels made from Vendor (AST technologies, model number 8000 WW 1000-2M) that houses the hollow fiber membranes with 100 kD cutoff (Vendor, AST technologies, Model no. 8000- WWOUT-IN-8080).

The two units are designed to deliver 1 .5m^3/h. The reverse osmosis (RO) membranes are made from thin film polyamide which consists of 1 x 4 inch pressure vessel made from composite material with pressure resistance up to 400 psi. The vessel holds two 4 inches special separation

membranes (manufactured in thin film polyamide with pH range 1-11 models BW30-4040 by DOW Film Tec.).
Membrane anti-scalent (Product NCS-106-FG made of phosphate in water with active ingredient of phosphoric acid disodium salt) is continuously dosed to the RO feed at concentration of 4 ppm in order to prevent deposition of divalent ions. The system is designed to remove major ions and heavy metals. The designed RO permeate capacity of the system is 0.45- 0.5 m^3/h [67].

2.3. Chemicals and Reagents

Pure standards of amoxicillin trihydrate, and cefuroxime axetil (> 99%) were obtained as a gift from Beit-Jalah pharmaceutical company (Palestine). Acetonitrile, methanol and water HPLC grade purchased from Sigma Aldrich, charcoal activated fine powder with particle size (≤ 60.0 micron), charcoal activated granules with particle size (≤ 700.0micron) were purchased from Sigma Aldrich, and octadecyltrimethylammonium (ODTMA)was purchased from Sigma chemical company[68].
C_{18} (5g) cartridges 6cc single use for general laboratory use were purchased form Waters company (Milford, MA, USA)

2.4. Methods (amoxicillin trihydrate, cefuroxime axetil)

2.4.1. Calibration curves using the solid phase cartridge

(a) Stock solution: Stock solution was prepared by dissolving amoxicillin trihydrate, cefuroxime axetil standards in water to a concentration of 1000 ppm for the use in section (b).
(b) Calibration curves using the solid phase cartridge: The C_{18} cartridges were preconditioned by passing first 10 mL of water through the cartridge and then 10 mL of methanol. The cartridges were then air dried. Several solutions of amoxicillin trihydrate and cefuroxime axetil with different concentrations (1.0, 5.0, 10.0, 20.0, 50.0, 100.0, 200.0 and 500.0 ppm) were prepared. 10 mL of each of these solutions was passed through the cartridge. The adsorbed amoxicillin trihydrate and Cefuroxime axetil was eluted from the adsorbent of the cartridge using 10 mL of methanol. Afterwards, 20 µl of the eluate was injected into the HPLC and analyzed using the HPLC conditions for amoxicillin trihydrate and cefuroxime axetil. Peak areas vs. concentration of amoxicillin trihydrate and cefuroxime axetil were then plotted, and correlation coefficient of the plots was recorded.

2.4.2. Efficiency of the wastewater treatment plant (WWTP) of Al-Quds University for removal of amoxicillin trihydrate and cefuroxime axetil.

The efficiency of different membranes (hollow fiber (HF-UF), spiral wound (SW-UF), activated carbon and reverse osmosis (RO) membranes, for the removal of amoxicillin trihydrate and cefuroxime axetil from wastewater was studied by spiking amoxicillin trihydrate and cefuroxime axetil in the storage tank of the wastewater treatment plant at a concentration of 20 ppm (by dissolving 10 g of amoxicillin trihydrate and cefuroxime axetil in the storage tank containing 500 liters of activated sludge wastewater).
Samples were taken from the following points of the WWTP: (1) storage tank (before running wastewater treatment plant) (2), (3), and (4) feed-, brine- and product-points of the HF-UF membrane, respectively (5) and (6) concentrated, and permeated-UF point of the HF-SW membrane, respectively (7) activated carbon point, and (8) reverse osmosis point. These sampling points are shown in (Figure 1, appendix).
These samples were treated using SPE C_{18} cartridge as follows: 10 mL of sample was loaded into the C_{18} cartridge, and allowed to pass through the cartridge by effect of gravity.
Amoxicillin trihydrate and cefuroxime axetil adsorbed on the C_{18} cartridge was then eluted using 10 mL of methanol.20 µl of the eluted solution was injected into the HPLC, and analyzed using the HPLC conditions for amoxicillin trihydrate and cefuroxime axetil methods of analysis.

2.4.3. Micelle-clay complex preparation

The micelle–clay complex was prepared by stirring 12mM of ODTMA (Figure 2, appendix) with 10g/L clay for 72hours at 37 ˚C. Suspensions were centrifuged for 20 minutes at 15 000 g, supernatants were discarded, and the complex was lyophilized. The obtained complex by virtue of its positive charge and hydrophobic region is capable of efficiently binding negatively charged organic molecules [77-79].

2.4.4 Adsorption studies onto micelle-clay complex and charcoal

2.4.4.1. Calibration curves (a) Stock solution: Stock solution was prepared by dissolving amoxicillin trihydrate and cefuroxime axetil standards in water to a concentration of 1000 ppm for the use in (b).

(b) Calibration curves: The following diluted solutions were prepared from the stock solution of amoxicillin trihydrate and cefuroxime axetil (0.5, 1.0,50,100,200,300, 400,500, 800, 1000 ppm) were prepared.
The absorption of each solution of amoxicillin trihydrate and cefuroxime axetil was determined using UV-spectrophotometer at (λ max)

2.4.4.2. Batch adsorption isotherms

Equilibrium relationships between adsorbents (micelle-clay complex and activated charcoal) and adsorbate (amoxicillin trihydrate, cefuroxime axetil) were described by adsorption isotherms, by studying the percentage of adsorbate removal occurred by both adsorbents (micelle-clay complex and activated charcoal) at different concentrations (100,200,300, 400, 500 ppm) prepared in distilled water pH 8.2 adjusted by 1M NaOH.

The following procedure was applied: 100 mL from each solution was transferred to 200 mL Erlenmeyer flask, 0.5 g of the micelle-clay complex or activated charcoal was added to the flask.
Then the flask was placed on the shaker machine for 180 minutes. Afterwards, each sample was centrifuged for 5 minutes, and filtered using 0.45µm filters.
Kinetic studies of the extent of adsorption was further determined by introducing 100 ml of 100 mg L^{-1}amoxicillin trihydrate and cefuroxime axetil solution in 250 ml flasks containing 0.5 g of either micelle-clay or charcoal and determining the amoxicillin trihydrate and cefuroxime axetil remaining time by time.
The absorption of each solution of amoxicillin trihydrate and cefuroxime axetil was determined using UV-

spectrophotometer at (λ max) of 273 and 278 nm for amoxicillin trihydrate and cefuroxime axetil respectively.

2.4.5. Column experiments

Column filter experiments were performed with 25/1 (w/w) mixtures of quartz sand and ODTMA-clay complex (20 cm layer) in a column of 25 cm length and 5 cm diameter prepared by mixing 4 g of micelle-clay complex and 96 g sand. The bottom of the column was covered with 3 cm layer of quartz sand.

Quartz sand was thoroughly washed by distilled water and dried at 105^0C for 24h prior its use. Wool layer of 2 cm was placed at the bottom of the column to prevent clogging. 1000 mL of 100 ppm amoxicillin trihydrate solution was passed through the column at a fixed flow rate of 2 mL min^{-1}.

For cefuroxime axetil, 1000 mL of 50 ppm cefuroxime axetil solution was passed through the column at a fixed flow rate of 2 mL min^{-1}. In certain experiments the columns included 4 g of activated carbon (GAC) mixed with sand as above.

Eluted fractions of 100 mL (each) were collected at chosen times, and analyzed for amoxicillin trihydrate and cefuroxime axetil concentration using UV-spectrophotometer at (λ max) of 273 nm 278 nm.All experiments described were conducted in triplicates.

3. Results and discussion

3.1. Amoxicillin Trihydrate

Amoxicillin trihydrate is a semi-synthetic β-lactam antibiotic (Figure3, appendix), the only phenolic penicillin which is used as an antibacterial drug [66].

Amoxicillin trihydrate is a white or almost white, crystalline powder with molecular weight of 419.4it is slightly soluble in water. It is frequently used antibiotic to treat many infections [76].

3.1.1. Calibration curve for Amoxicillin Trihydrate using solid phase extraction cartridge (SPE)

The calibration curve was obtained by plotting peak area versus concentration (in ppm) and is displayed in (Figure 4, appendix) (seven data points) for amoxicillin trihydrate. The plot showed excellent linearity with correlation coefficient (R^2) of 0.999.

3.1.2. HPLC conditions for analysis of Amoxicillin Trihydrate

C18 column 250mm x 4.6mm, wavelength = 273 nm, Flow rate = 1.0 mL/min, mobile phase: 75:25 water and acetonitrile.

3.1.3. Efficiency of the wastewater treatment plant (WWTP) at Al-Quds University for the removal of Amoxicillin Trihydrate

The efficiency of the wastewater treatment plant (WWTP) at Al-Quds University for amoxicillin trihydrate removal was studied. The result demonstrated that amoxicillin trihydrate was 58.93% removed at the hollow fiber stage (UF-HF), while about 90.33% of amoxicillin trihydrate was removed at the spiral wound (SW) stage, (Tables S1 and S2, supplementary Data). At the activated carbon adsorbent point of the wastewater treatment plant, 96.47% of amoxicillin trihydrate was removed. The results also indicated that complete removal (100%) of amoxicillin trihydrate was achieved after passing through the reverse osmosis membrane (RO) (Figures 5, 6 and 7, appendix).

3.1.4. Calibration curve for Amoxicillin Trihydrate using UV-visible spectrophotometer

The calibration curve was obtained by plotting absorption versus concentration of amoxicillin trihydrate and is displayed in (Figure 8, appendix) (8 data points). The Figure shows excellent linearity in the range 0.5-1000 ppm with correlation coefficient (R^2) of 0.999.

3.1.5. Adsorption studies of Amoxicillin Trihydrate on a micelle-clay complex (ODTMA) and activated charcoal.

Adsorption mechanism depends on the physicochemical properties of the pharmaceutical and the aquifer media properties. Adsorption of amoxicillin trihydrate onto a micelle-clay complex and charcoal adsorbents was investigated and described in this section.

3.1.5.1. Adsorption of Amoxicillin Trihydrate on a micelle-clay complex (ODTMA) and activated charcoal

Amoxicillin trihydrate removal by a micelle-clay complex and activated charcoal were studied. Samples were taken at different time intervals (0 -180 minutes). The results revealed that activated charcoal was effective for the removal of amoxicillin trihydrate from spiked samples (100 ppm) at pH 8.2. The removal was about 98.5% and was achieved after three hours.

The capacity of the micelle-clay complex and activated charcoal towards adsorption of amoxicillin trihydrate was quite comparable. The results showed that the adsorption of amoxicillin trihydrate on the micelle-clay complex is faster when compared to that on the activated charcoal (about 81.6% of amoxicillin trihydrate was removed in the first 5 minutes while only 50.2% of amoxicillin trihydrate was removed by the activated charcoal. As shown in (Figures 9 and 10, appendix) and Tables S3 and S4 (Supplementary Data).

3.1.5.2. Analysis of Adsorption Isotherms

Equilibrium relationships between adsorbents (micelle-clay complex and charcoal) and adsorbate (i.e. amoxicillin trihydrate) are described by adsorption isotherms. The most common model for adsorption process is Langmuir adsorption isotherms which consider the most widely used modeling for equilibrium data and determination of the adsorption capacity [77].

It is a linear form and represented by the following equation:

$$C_e/Q_e = 1/ (K\ Q_{max}) + C_e/Q_{max} \quad \text{..... Eq. (1)}$$

Where:

C_e: equilibrium concentration of amoxicillin trihydrate (mgL^{-1}).

Q_e: the equilibrium mass of the adsorbed amoxicillin trihydrate per gram of complex or activated carbon ($mg.g^{-1}$)

K: Langmuir binding constant k ($L\ mg^{-1}$)

Q_{max}: maximum mass of amoxicillin trihydrate removed per gram of complex ($mg.g^{-1}$).

For this study the adsorption of amoxicillin trihydrate of five concentrations (100, 200, 300, 400, and 500 ppm) on the

micelle-clay complex and activated charcoal were studied, then C_e, and Q_e were calculated as in Tables S5 and S6 (Supplementary Data). C_e/Q_e vs. C_e was plotted for amoxicillin trihydrate adsorbed onto both micelle-clay complex and activated charcoal (Figure 11, appendix).

The two parameters Q_{max} and K values for adsorption of amoxicillin trihydrate on micelle-clay complex and activated charcoal can be calculated from the slopes and y-intercepts of the equations obtained from the plots (Q_{max} = slope^{-1}, K = (y-intercept)$^{-1}$(Q_{max})$^{-1}$). Table S7 (Supplementary Data) shows the values for Q_{max} and k for amoxicillin trihydrate adsorbed on both micelle-clay complex and activated charcoal.

Were the results of K and Q_{max} are repeated as value ± SD; SD: standard deviation of three replicates.

The results demonstrated that both adsorbents, micelle-clay complex and activated charcoal, have the same efficiency for the removal of amoxicillin trihydrate as both Q_{max} are comparable (90.91 mg of amoxicillin trihydrate per gram of complex, and 100 mg of amoxicillin trihydrate per gram of activated charcoal) , As shown in (Figure 11, appendix) the relationship between C_e/Q_e and C_e is linear for both the micelle-clay complex and activated charcoal with R^2 greater than 0.98 which indicates that the adsorption of amoxicillin trihydrate onto micelle-clay and charcoal follows the Langmuir isotherm model.

3.1.6. Column Experiments

1000 mL of amoxicillin trihydrate (100ppm) were eluted in triplicate through column filters.

The results demonstrate that a filter which includes the micelle-clay complex (ODTMA)-montmorillonite is very efficient in purifying water from amoxicillin trihydrate compared to that removed by activated charcoal. (Table S8, supplementary Data).

Comparing results of batch adsorption kinetics reported in (Figure 12, appendix) (100 ppm solution/0.5 g L^{-1} adsorbent) with those of Figure 13, it is evident that the flow rate used (2 mL min^{-1}) can be suitable for the filtration of 1000 mL of 100 ppm amoxicillin solution, yielding a complete removal of the drug.

3.2. Cefuroxime axetil

Cefuroxime axetil(CA), (RS)-1 hydroxyethyl (6R,7R)-7-[2-(2-furyl) glyoxyl-amido] -3- (hydroxylmethyl -8-oxo-5-thia-1- azabicyclo[4.2.0]-oct-2-ene-2- carboxylate,72-(Z)-(O- methyl-oxime),1-acetate3- carbamate) (Figure 13, appendix) is a second generation oral cephalosporin antibiotic used to treat or prevent infections that are proven or strongly suspected to be caused by bacteria.

It is an acetoxyethylester prodrug of cefuroxime which is effective orally. The activity depends on in vivo hydrolysis and release of cefuroxime [74], cefuroxime axetil is a white or almost white powder and is slightly soluble in water [70].

3.2.1. Calibration curve for cefuroxime axetil using solid phase extraction cartridge (SPE)

The calibration curve was obtained by plotting peak area versus concentration (in ppm) and is displayed in (Figure 14, appendix) (seven data points) for cefuroxime axetil they showed excellent linearity with correlation coefficient (R^2) of 0.999. This indicates that the method used is quite reliable.

3.2.2. HPLC conditions for analysis of Cefuroxime axetil

C_{18} column 250 mm x 4.6 mm, wavelength = 278 nm, Flow rate = 1.2 mL/min, mobile phase: 60:40 of water and acetonitrile.

3.3. Efficiency of the wastewater treatment plant (WWTP) at Al-Quds University for the removal of Cefuroxime axetil

The efficiency of the wastewater treatment plant (WWTP) at Al-Quds University for cefuroxime axetil removal was studied. Result demonstrated that cefuroxime axetil was 70.90% removed at hollow fiber stage (UF-HF), while about 91.27% of cefuroxime axetil was removed at spiral wound (SW) stage, (Tables S9 and S10, Supplementary Data).

At the activated carbon adsorbent point of the wastewater treatment plant, 96.03% of cefuroxime axetil was removed. The results also indicated that complete removal (100%) of cefuroxime axetil was achieved after passing through the reverse osmosis membrane (RO), (Figures 15-17, appendix).

3.3.1. Calibration curve for Cefuroxime axetil using UV-visible spectrophotometer

The calibration curve was obtained by plotting absorption versus concentration of Cefuroxime axetil and is displayed in (Figure18, appendix) (8 data points). The Figure shows excellent linearity in the range 50-1000 ppm with correlation coefficient (R^2) of 0.999.

3.4. Adsorption studies of cefuroxime axetil on a clay micelle complex (ODTMA) and activated charcoal

Adsorption mechanism depends on the physicochemical properties of the pharmaceutical and the aquifer media properties. Adsorption of cefuroxime axetil onto a micelle clay complex and charcoal adsorbents was investigated and described in this section.

3.4.1. Adsorption of cefuroxime axetil on a clay micelle complex (ODTMA) and activated charcoal

Cefuroxime axetil removal by a micelle-clay complex and activated charcoal as studied. Samples were taken at different time intervals (0 -180 minutes). The results revealed that the micelle-clay complex is effective for the removal of cefuroxime axetil from spiked samples (100 ppm) at pH 8.2. The removal was about 95.2% and was achieved after three hours. As shown in Tables S11 and S12 (Supplementary Data)

The capacity of the clay micelle complex and activated charcoal towards adsorption of cefuroxime axetil was quite comparable. The results showed that the adsorption of cefuroxime axetil on the micelle clay complex is faster when compared to that on the activated charcoal (about 72.2% of cefuroxime axetil was removed in the first 5 minutes while only 49.5% of cefuroxime axetil was removed by the activated charcoal. As shown in Tables S13 andS14 (Supplementary Data) and Figures19 and 20 (Appendix).

Were the results of K and Q_{max} are repeated as value ± SD; SD: standard deviation of three replicates the data fitted the Langmuir isotherm with R^2 0.980 for activated charcoal and 0.999 for the micelle-clay complex (Figure 21, appendix).

The Langmuir constants (k and Q_{max}) were calculated and are presented in Table S15 (Supplementary Data).

Inspection of Table S15 (Supplementary data) revealed that the adsorption isotherm with micelle-clay complex has larger Q_{max} and k values than those with activated carbon, thus rendering the former as better adsorbent for removal of cefuroxime axetil than the latter.

3.4.2. Column Experiments

1000 ml of cefuroxime axetil (50ppm) were eluted in triplicate through column filters. The results (Table S16) (Supplementary Data) indicate a significant advantage of the micelle-clay filter in removing cefuroxime axetil compared to that removed by activated charcoal. This was not surprising, since the results for adsorption isotherm and in particular the kinetics have clearly shown that the micelle-clay-complex was more efficient than activated carbon in removing cefuroxime axetil from water (Figure 22, appendix).

4. Summary and conclusions

Advanced wastewater treatment plant utilizing ultra filtration, activated carbon and RO showed that (UF-HF) alone and (UF-SW) are not efficient in removing amoxicillin trihydrate and cefuroxime axetil to safe level, but addition of activated carbon and RO enable their complete removal. Adsorption studies on micelle clay complex (ODTMA) and charcoal revealed that both adsorbents are efficient for the removal of amoxicillin trihydrate and cefuroxime axetil.

The large effectiveness and removal capacity of ODTMA-clay-micelles complex are due to a relatively high affinity of adsorption of the anionic amoxicillin trihydrate and cefuroxime axetil by the relatively large number of positively charged and hydrophobic sites of the micelle-clay complex based on ODTMA.

5. References

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Appendix

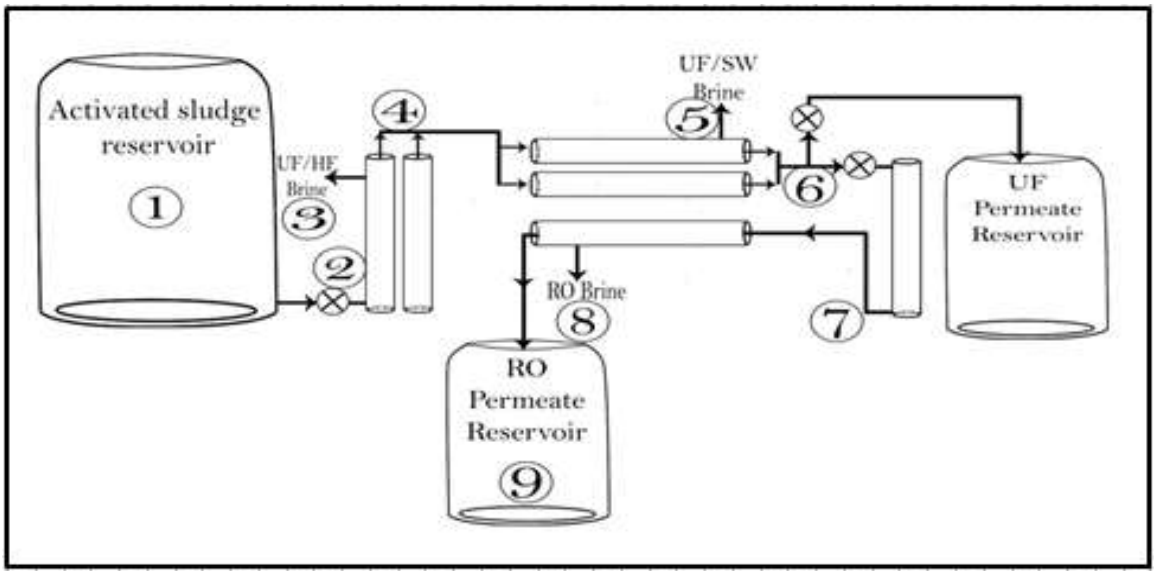

Figure 1: Flow diagram showing the process of wastewater treatment plant which consists of HF-UF filters (hollow fiber) and SW-UF (spiral wound), activated carbon and RO filters. Sampling locations are indicated by numbers.

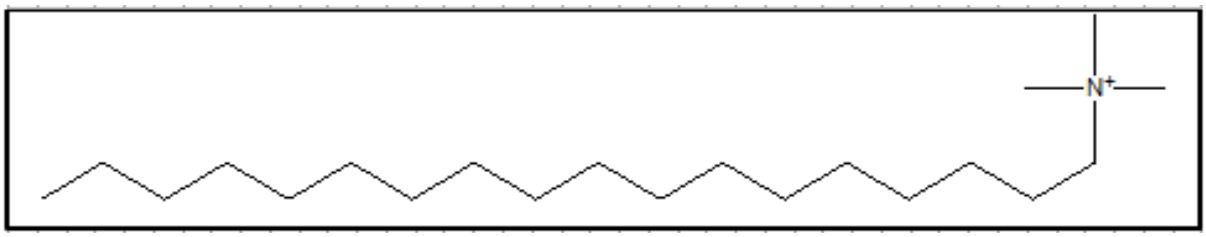

Figure2: Octadecyltrimethylammonium (ODTMA)

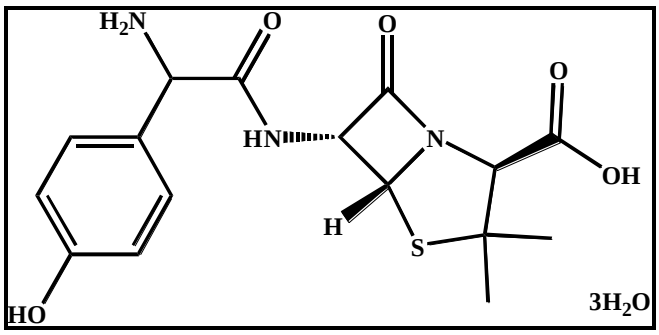

Figure3: Structure of amoxicillin trihydrate

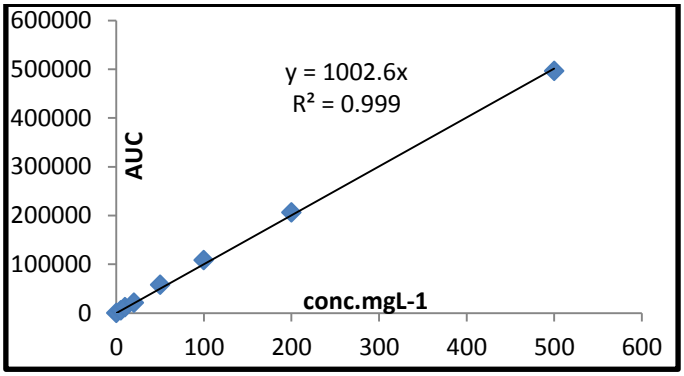

Figure 4: Calibration curve by using SPE for amoxicillin trihydrate.

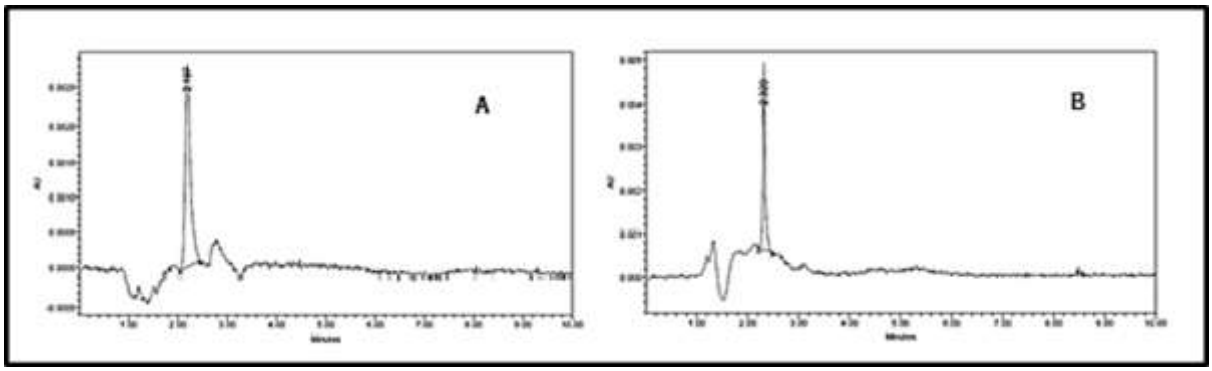

Figure 5: Chromatograms showing the a) initial concentration of amoxicillin trihydrate, and, b) after running the HF-UF point.

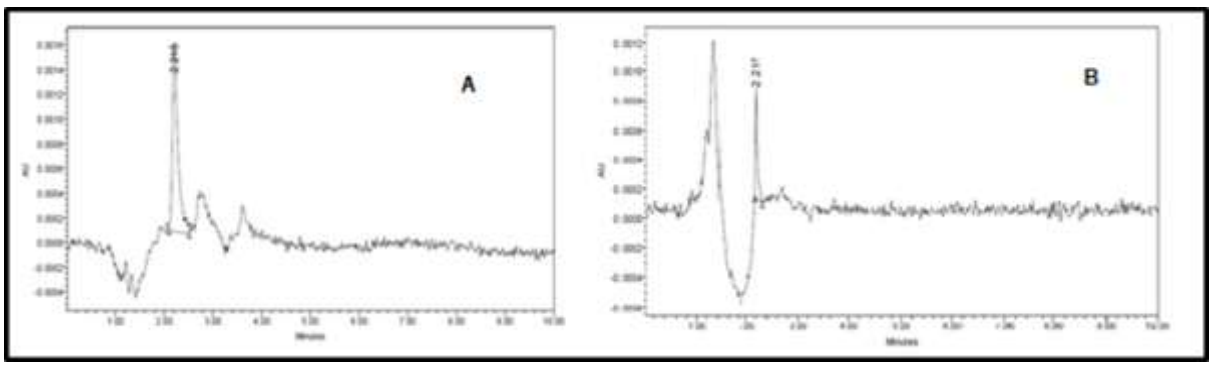

Figure 6: Chromatogram showing the concentration of amoxicillin trihydrate a) before and b) after running the SW-UF point

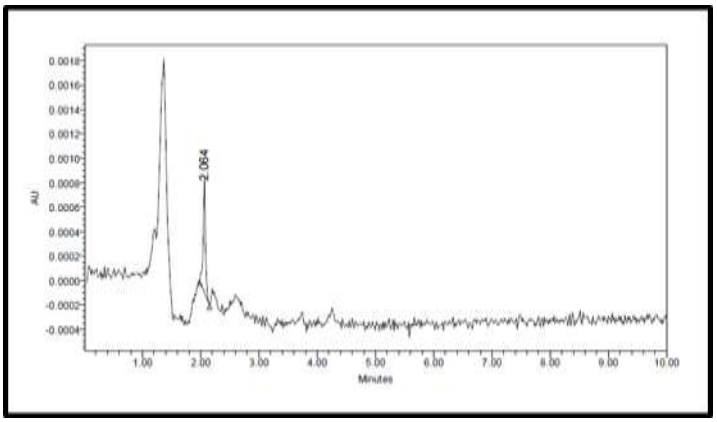

Figure7: Chromatogram showing the concentration of amoxicillin trihydrateafter running activated charcoal adsorbent point.

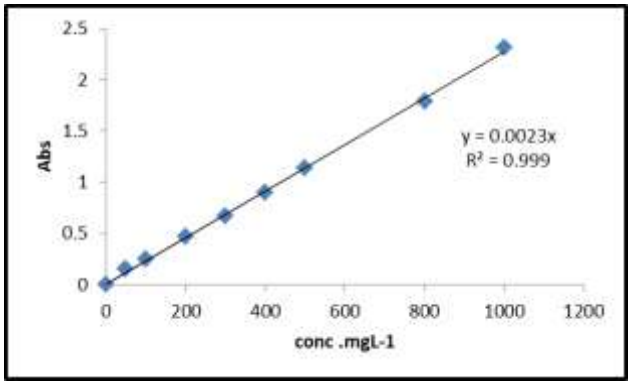

Figure 8:calibration curve of amoxicillin trihydrate

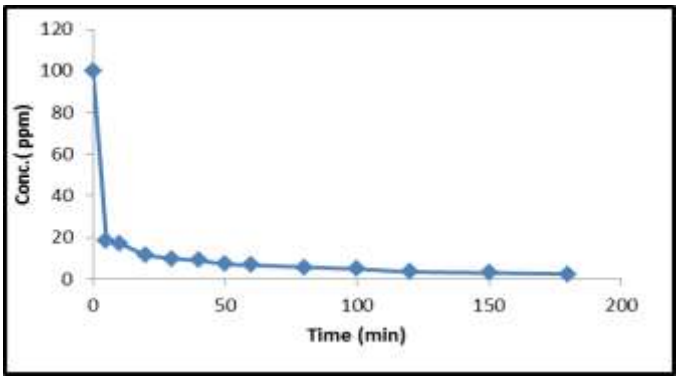

Figure 9: Adsorption of amoxicillin trihydrate by micelle- clay complex (ODTMA) at pH 8.2.

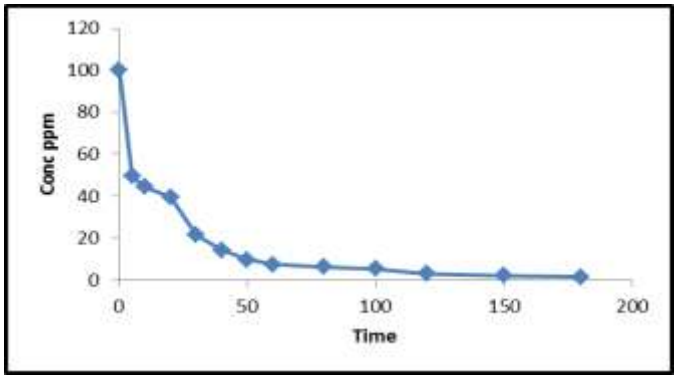

Figure 10: Adsorption of amoxicillin trihydrate by charcoal at pH 8.2.

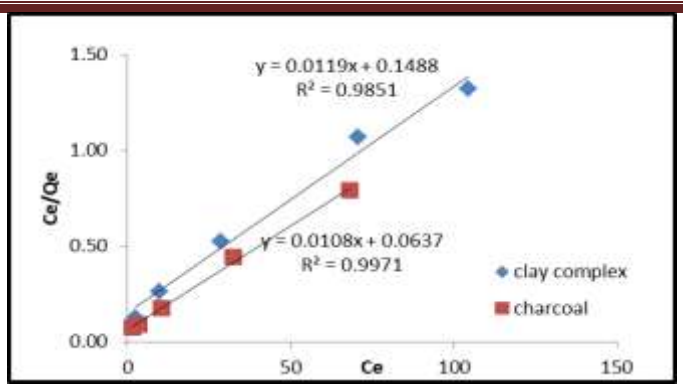

Figure 11: Langmuir isotherms for the removal of amoxicillin trihydrate by micelle-clay complex and by activated charcoal (■) (pH 8.2, 25°C) .

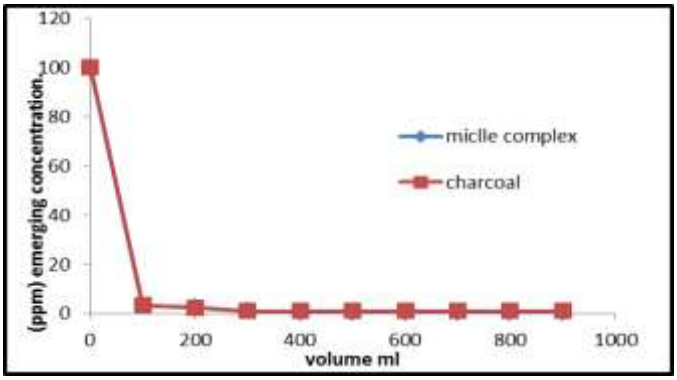

Figure12: Conc. of amoxicillin trihydrate Vs. volume of samples were taken from micelles clay and charcoals column.

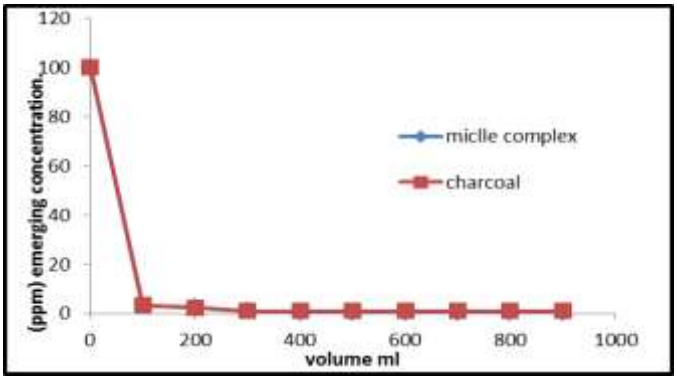

Figure 13: Structure of cefuroxime axetil

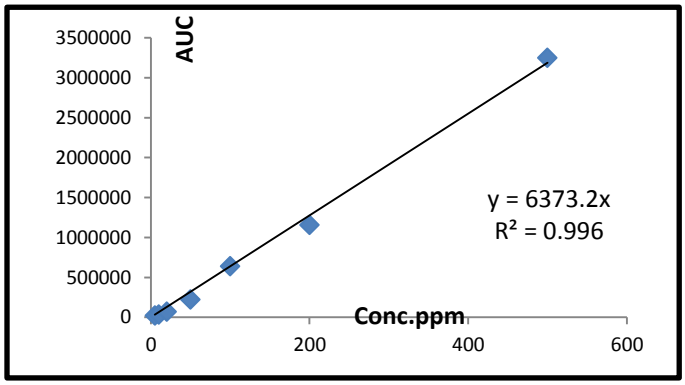

Figure 14: Calibration curve by using SPE for cefuroxime axetil.

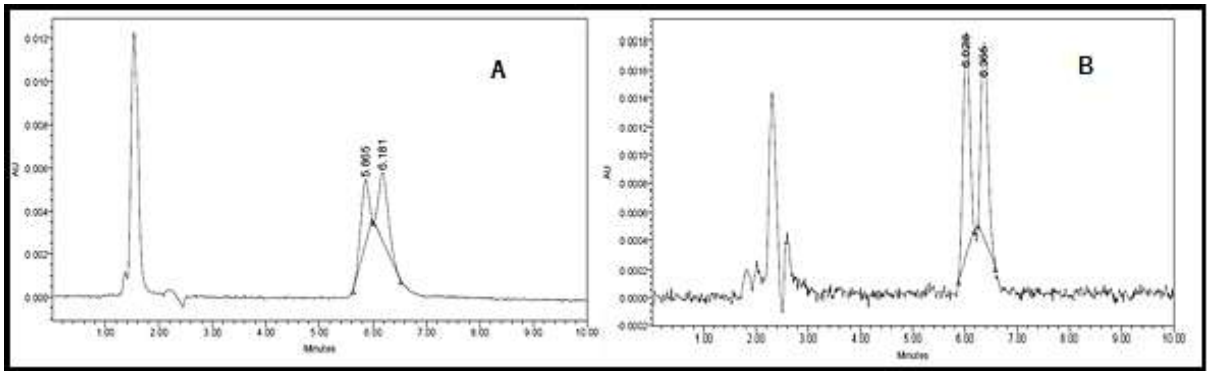

Figure 15: Chromatograms showing the a) initial concentration of cefuroxime axetiland b)after running the HF-UF point.

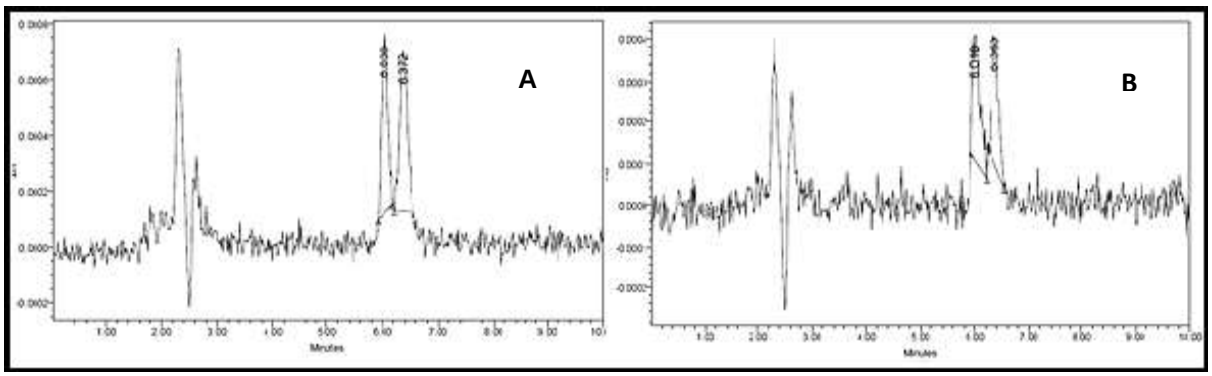

Figure 16: Chromatogram showing the concentration of cefuroxime axetila) before and b)after running the SW-UF point**.**

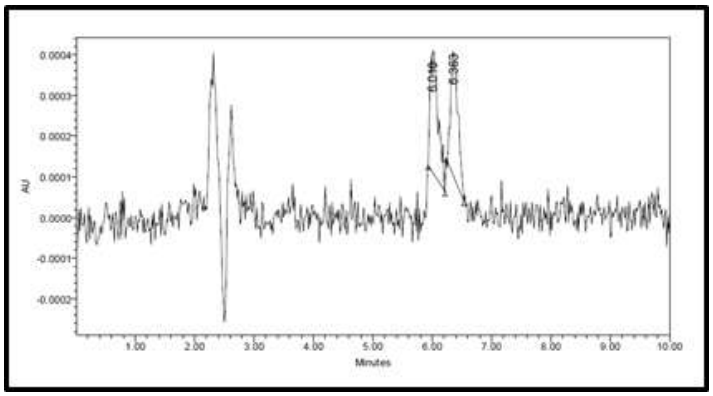

Figure 17: Chromatogram showing the concentration of cefuroxime axetil after running activated charcoal adsorbent point.

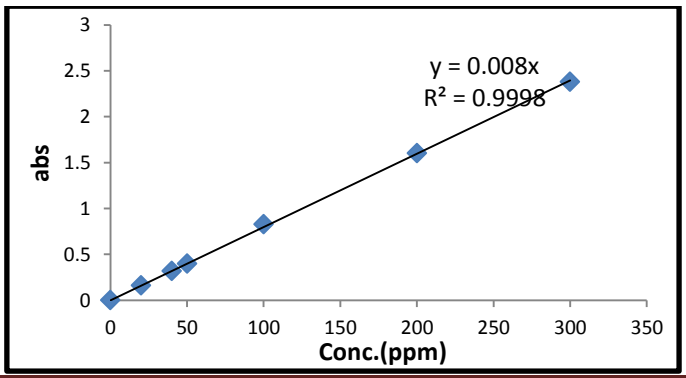

Figure 18: calibration curve of cefuroxime axetil.

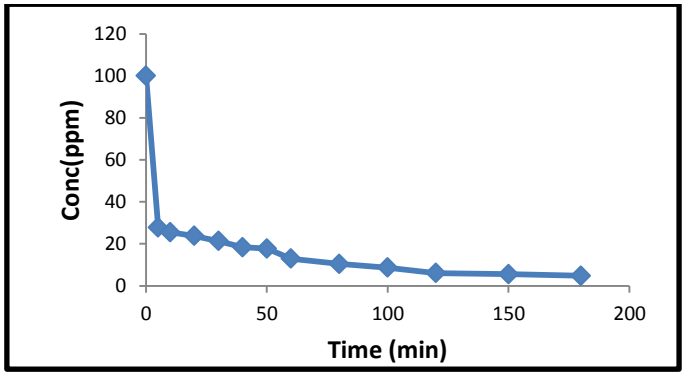

Figure19: Adsorption of cefuroxime axetil by micelle clay complex (ODTMA) at pH 8.2

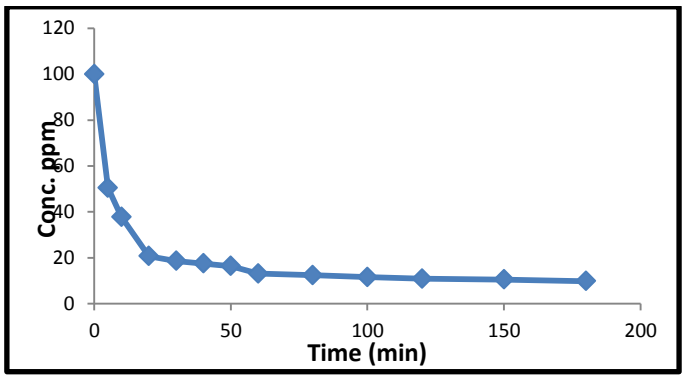

Figure 20: Adsorption of cefuroxime axetil by charcoal at pH 8.2

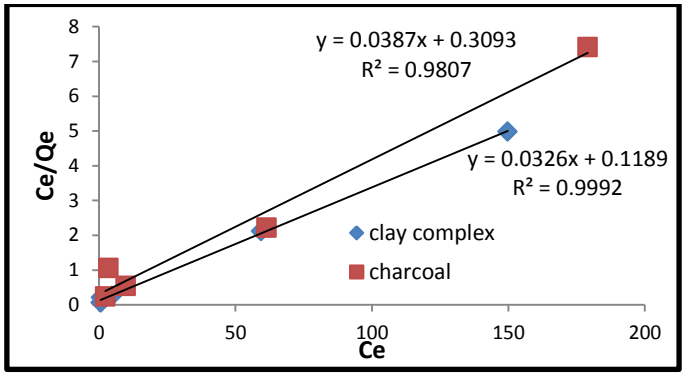

Figure 21: Langmuir isotherms for the removal of cefuroxime axetil by activated charcoal (■) and by clay complex (◆). (pH 8.2, 25°C) .

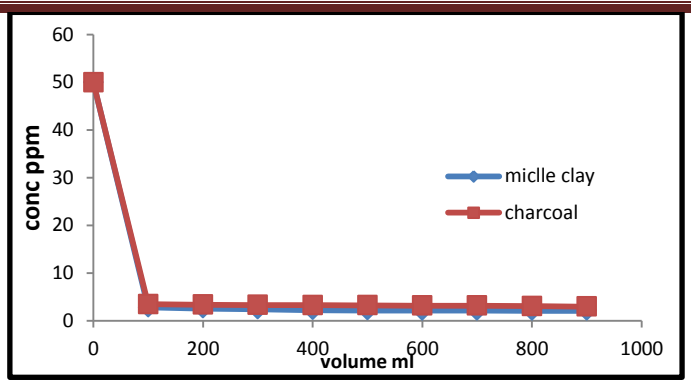

Figure 22: Conc. Of Cefuroxime Axetil Vs. Volume Of Samples Were Taken From Clay Micelles And Charcoals Column.

Supplementary Data

Table S1: Removal of amoxicillin trihydrate (AMX) through the hollow fiber (UF-HF), spiral wound (UF-SW), activated carbon adsorbent and reverse osmosis from the wastewater treatment plant at Al-Quds university.

No	Sample location name		AMX (ppm) Trial 1	AMX (ppm) Trial 2	AMX (ppm) Trial 3
1	Blank (before addition AMX)		0	0	0
2	The initial concentration of AMX in storage tank (after addition of AMX)		19.1	18.5	19.5
3	HF-UF	Feed point	18	17.6	18
		Brine point	6.03	11.85	12.33
		Product point	11.97	5.75	5.67
4	HF-SW	Concentrated UF point	9.69	4.27	3.72
		Permeated UF point	2.10	1.48	1.95
5	Activated carbon point		1.19	0.41	0.41
6	Reverse osmosis	Permeated RO point	0.0	0.0	0.0

Table S2: Accumulative % removal of amoxicillin trihydrate.

Trial No.	Hollow fiber (HF)	Spiral wound (SW)	Activated carbon (AC)	Reverse osmosis (RO)
1	37.00%	89.00%	93.76%	100.00%
2	68.90%	92.00%	97.76%	100.00%
3	70.90%	90.00%	97.90%	100.00%
Average	58.93%	90.33%	96.47%	100.00%
SD	12.1	1.52	2.35	0.057

Table S3: Percentage removal of amoxicillin trihydrate by micelle-clay complex (ODTMA) at pH 8.2

Time(minutes)	Abs	Conc.(ppm)	Mass(mg)	%Removal
0	0.249	100	10	0
5	0.042	18.4	1.84	81.6
10	0.040	17.3	1.73	82.7
20	0.026	11.5	1.15	88.5
30	0.023	9.8	0.98	90.2
40	0.021	9	0.9	91
50	0.017	7.2	0.72	92.8
60	0.016	6.8	0.68	93.2
80	0.013	5.7	0.57	94.3
100	0.012	5	0.5	95
120	0.008	3.5	0.35	96.5
150	0.007	3	0.3	97
180	0.006	2.48	0.248	97.52

Table S4: Percentage removal of amoxicillin trihydrate by activated charcoal.

Time(Minutes)	Abs	Conc.(ppm)	Mass(mg)	% Removal
0	0.249	100	10	0
5	0.115	49.8	4.98	50.2
10	0.102	44.4	4.44	55.6
20	0.091	39.6	3.96	60.4
30	0.049	21.5	2.15	78.5
40	0.033	14.4	1.44	85.6
50	0.022	9.7	0.97	90.3
60	0.017	7.5	0.75	92.5
80	0.015	6.4	0.64	93.6
100	0.013	5.5	0.55	94.5
120	0.007	3.2	0.32	96.8
150	0.005	2.1	0.21	97.9
180	0.003	1.5	0.15	98.5

Table S5: Concentrations in equilibrium obtained for adsorption test of amoxicillin trihydrate onto the adsorbent micelle-clay .(pH 8.2 and 25°C)

Conc. ppm	Mass(mg) (Initial)	Abs (T=180 min)	Conc. (T=180) (Ce)(ppm)	Mass(mg) (Final)	$M_I - M_F$	Q $(M_I-M_F/0.5)$	Ce/Qe
100	10	0.006	2.47	0.247	9.753	19.506	0.13
200	20	0.020	9.9	0.99	19.01	38.02	0.26
300	30	0.057	28.47	2.847	27.153	54.306	0.52
400	40	0.141	70.6	7.06	32.94	65.88	1.07
500	50	0.209	104.55	10.455	39.545	79.09	1.32

Table S6: Concentrations in equilibrium obtained for adsorption test of amoxicillin trihydrate onto the adsorbent activated charcoal .(pH 8.2 and 25°C)

Conc. ppm	Mass(mg) (Initial)	Abs (T=180 min)	Conc. (T=180) (Ce)(ppm)	Mass(mg) (Final)	$M_I - M_F$	Q $(M_I-M_F/0.5)$	Ce/Qe
100	10	0.003	1.5	0.15	9.85	19.7	0.08
200	20	0.007	3.46	0.346	19.654	39.308	0.09
300	30	0.021	10.29	1.029	28.971	57.942	0.18
400	40	0.065	32.52	3.252	36.748	73.496	0.44
500	50	0.136	68.15	6.815	43.185	86.37	0.79

Table S7: Langmuir adsorption parameters (k and Q_{max}) and the correlation coefficient (R^2) values obtained from the adsorption of amoxicillin trihydrate on both adsorbents, a micelle-clay complex and activated charcoal.

Pharmaceutical	Adsorbents	Langmuir		
		K (L/mg)	Q_{max} (mg/g)	R^2
Amoxicillin trihydrate	Micelle-clay complex	0.229±0.001	90.91 ± 0.86	0.985
	Charcoal	0.158±0.001	100 ± 0.35	0.997

Table S8: Removal of amoxicillin trihydrate by filtration of its solution (100 ppm) through a laboratory filter, which included either a micelle-clay complex , or activated carbon mixed with excess sand at 1:25 (w/w).

Vol. filtrated (ml)	Conc. (ppm)	Column type	Emerging Conc. (ppm)	% Removal
1000	100	micelle-clay	0.5 ±0.001	99.5
1000	100	activated carbon	1±0.002	99

Table S9: Removal of cefuroxime axetilthrough (CEF) the hollow fiber (UF-HF), spiral wound (UF-SW), activated carbon adsorbent and reverse osmosis from the wastewater treatment plant at Al-Quds university.

No	Sample location name		CEF (ppm) Trial 1	CEF (ppm) Trial 2	CEF (ppm) Trial 3
1	Blank (before addition CEF)		0	0	0
2	The initial concentration of CEF in storage tank (after addition of CEF)		19.5	19.1	19.5
3	HF-UF	Feed point	19.5	18.6	18
		Brine point	13.5	13.20	12.10
		Product point	5.66	5.73	5.89
4	HF-SW	Concentrated UF point	3.73	4.10	4.04
		Permeated UF point	1.89	1.34	1.85
5	Activated carbon point		0.88	0.63	0.80
6	Reverse osmosis	Permeated RO point	0.0	0.0	0.0

Table S10: Accumulative % removal of cefuroxime axetil.

Trial No.	Hollow fiber (HF)	Spiral wound (SW)	Activated carbon (AC)	Reverse osmosis (RO)
1	71.00%	90.30%	95.50%	100.00%
2	71.90%	93.00%	96.70%	100.00%
3	69.80%	90.50%	95.90%	100.00%
Average	70.90%	91.27%	96.03%	100.00%
SD	0.01	0.02	0.01	0.0

Table S11: Percentage removal of cefuroxime axetil by micelle clay complex (ODTMA) at pH 8.2

Time	Abs	Conc. Ppm	Mass	% Removal
0	0.827	100	10	0
5	0.222	27.75	2.775	72.25
10	0.204	25.5	2.55	74.5
20	0.190	23.77	2.377	76.23
30	0.170	21.28	2.128	78.72
40	0.146	18.37	1.837	81.63
50	0.141	17.7	1.77	82.3
60	0.103	12.9	1.29	87.1
80	0.083	10.38	1.038	89.62
100	0.069	8.69	0.869	91.31
120	0.048	6.09	0.609	93.91
150	0.044	5.5	0.55	94.5
180	0.038	4.8	0.48	95.2

Table S12: Percentage removal of cefuroxime axetil by activated charcoal

Time	Abs	Conc. (ppm)	mass	% Removal
0	0.827	100	10	0
5	0.404	50.5	5.05	49.5
10	0.302	37.8	3.78	62.2
20	0.165	20.7	2.07	79.3
30	0.148	18.6	1.86	81.4
40	0.140	17.5	1.75	82.5
50	0.132	16.4	1.64	83.6
60	0.104	13.1	1.31	86.9
80	0.099	12.4	1.24	87.6
100	0.092	11.6	1.16	88.4
120	0.087	10.9	1.09	89.1
150	0.084	10.5	1.05	89.5
180	0.078	9.80	0.98	90.2

Table S13: Concentrations in equilibrium obtained for adsorption test of cefuroximaxetil onto the adsorbent micelle clay (pH 8.2 and 25°C).

Conc. ppm	Mass(mg) (Initial)	Abs (T=180 min)	Conc. (T=180) (Ce)(ppm)	Mass(mg) (Final)	$M_I - M_F$	Q $(M_I-M_F/0.5)$	Ce/Qe
20	2	0.006	0.8	0.08	1.92	3.84	0.21
50	5	0.005	0.65	0.065	4.935	9.87	0.07
100	10	0.038	4.8	0.48	9.52	19.04	0.25
200	20	0.475	59.4	5.94	14.06	28.12	2.11
300	30	1.198	149.73	14.973	15.027	30.05	4.98

Table S14: Concentrations in equilibrium obtained for adsorption test of cefuroximaxetil onto the adsorbent activated charcoal .(pH 8.2 and 25°C)

Conc. ppm	Mass(mg) (Initial)	Abs (T=180 min)	Conc. (T=180) (Ce)(ppm)	Mass(mg) (Final)	$M_I - M_F$	Q $(M_I-M_F/0.5)$	Ce/Qe
20	2	0.028	3.5	0.35	1.65	3.3	1.06
50	5	0.018	2.3	0.23	4.77	9.54	0.24
100	10	0.078	9.8	0.98	9.02	18.04	0.54
200	20	0.491	61.4	6.14	13.86	27.72	2.22
300	30	1.433	179.1	17.91	12.09	24.18	7.41

Table S15: Langmuir adsorption parameters (k and Q_{max}) of cefuroxime axetil onto micelle clay complex and activated charcoal adsorbents.

Pharmaceutical	Adsorbents	Langmuir		
		K (L/mg)	Q_{max} (mg/g)	R^2
Cefuroximaxetil	Micelle-clay complex	0.271±0.003	31.25 ± 0.65	0.999
	Charcoal	0.122±0.002	26.31 ± 0.70	0.980

Table S16: Removal of Cefuroxime axetil by filtration of its solution (50 ppm) through a laboratory filter, which included either a micelle-clay complex , or activated carbon mixed with excess sand at 1:25 (w/w).

Vol. filtrated (ml)	Conc. (ppm)	Column type	Emerging Conc. (ppm)	% Removal
1000	50	micelle-clay	2.10±0.003	95.79
1000	50	activated carbon	3.5±0.002	93