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Treatment of Well Water Contaminated with Septic Tank Effluent Using a Modified Compacted Sand Filter

M. Harikumar, P. Sikha, M. P. Amrutha, F. Jamshiya, and T. Arathi

Abstract The flood that occurred in the month of August 2018 had brought severe damages all over Kerala. The major problem after the flooding was the contamination of well water with septic waste. This problem created a situation where proper drinking water was not available to the victims. A similar situation was faced by the residents of Velam Panchayath of Kozhikode district, where the well water was contaminated using septic tank effluent. Disinfection using bleaching powder was the only method adopted by the local authorities to make the well water potable. Since the septic waste contains toxic content and affects the human life significantly when consumed, an efficient and economic method of well water treatment is very necessary. The well water should be treated effectively after it is pumped into the overhead tank and then used for domestic purposes. This requires the designing of a filter in which the water gets purified in stages. The purified water coming out of the filter should be tested and made sure for drinking. The aim of this paper is to make a keen attention towards this problem and to implement some control measures to minimize this problem to certain extent by fabricating a Modified Drawer Compacted Sand Filter (MDCSF). This model consists of different drawers each filled with gravel, sand, activated charcoal, and silver-impregnated sand. Although the conventional drawer compacted sand filter has been used in the treatment of contaminated water, in this paper, a modification is made to the existing design by the introduction of forced aeration, using a silver-impregnated sand layer and an activated charcoal layer.

Keywords Septic tank effluent · Modified drawer compacted sand filter · Well water treatment · Coliform · BOD · COD · TDS

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1 Introduction

Contamination of drinking water sources by sewage can occur from raw sewage overflow, leaking sewer lines, and the application of sludge and partially treated wastewater to land. Septic tank effluent (STE) is the effluent discharged out of a septic tank. During natural disasters such as flooding, this effluent may get mixed up with well water, making them unfit for use and creating water scarcity problems [1]. The pollution and ill effects due to STE are not properly investigated or monitored. This study aims to fabricate a modified drawer compacted sand filter that relies upon different methods of filtration like straining, absorption, adsorption, biological action, etc. This process is undertaken by different layers of gravel, sand, silver-coated sand, and activated charcoal. Synthetic septic tank effluent is prepared under laboratory conditions and is filtrated through the Modified Drawer Compacted Sand Filter (MDCSF). The filtered water can be tested and compared with drinking water standards.

2 Objectives of the Study

The primary objectives of the study are outlined as follows:

- To synthetically produce the septic tank effluent (STE) in a laboratory.
- To check the chemical and biological characteristics of STE such as
  - Biological oxygen demand (BOD)
  - Chemical oxygen demand (COD)
  - Coliform content
  - Phosphate
  - TDS.
- To find the treatment efficiency at varying conditions of hydraulic loading rate and pH of drawer compacted sand filter (DSCF) with silver-impregnated sand.
- To get potable water from the filter.

3 Preparation of STE

Since it is inconvenient to take the effluent directly from the septic tank, the STE is synthetically prepared by using certain chemicals in their respective proportions. Table 1 shows the composition of STE and their concentration in milligram, for 1L of distilled water. The sample prepared is of 100× concentrated solution and is stored at 1 °C for up to one week. The daily requirement of the sample is satisfied by suitably diluting the master sample, with tap water.

Table 1 Composition of STE

Sl. No.	Composition	Concentration (mg)
1	Peptone	160
	Meat extract	110
3	Urea	30
4	Sodium chloride	7
5	Calcium chloride	4
6	Magnesium sulphate heptahydrate	2
7	Dipotassium hydrogen phosphate	28

4 Materials

4.1 Gravel

Conventionally, several different types of media have been used for filtration. Sand or a gravel-type filter has a high porosity and permeability due to which water can flow through it, often by gravity drainage [2]. The tortuous nature of the flow path and the comparatively small pore diameters slow the flow and physically trap suspended solids. Gravel filters are most effective in reducing the turbidity of water. On the other hand, pathogens are rarely removed. Gravel sample passing through a sieve of 4.75 mm and retaining on a 2.36 mm sieve was used for filtration. The sample is washed with clear water and dried in sun.

4.2 Sand

Sand has a very important role to play in the filtration process [3]. In MDCSF, sand was used as a major filtering medium. Each drawer of the filter is filled with different grades of sand. The purity of water increases with the fineness of sand. Different types of sand with varying particle size are used in filter fabrication. This includes sand retained on 1.18 mm, 600 μm and 75 μm sieve. The drawer containing sand sample retained on 1.18 mm size is placed below gravel layer. This is followed by a drawer with 600 μm silver treated sand, which is in turn, followed by 75 μm sand.

4.3 Silver-Coated Sand

It is very well known that silver has been shown to have general antibacterial properties against a range of both Gram-negative (e.g. *Acinetobacter*, *Escherichia*, *Pseudomonas*, *Salmonella,* and *Vibrio*) and Gram-positive bacteria (e.g. *Bacillus*, *Clostridium*, *Enterococcus*, *Listeria*, *Staphylococcus,* and *Streptococcus*) [4].

4.3.1 Preparation of Silver-Coated Sand

Silver-coated sand was obtained by treating sand with silver nitrate. The silver content present in purified water can resist the growth of unhealthy organisms. The steps for preparation of silver-coated sand are outlined below:

- About 500 g of graded, washed, and dried sand was mixed with 1 g silver nitrate dissolved in 1 L of distilled water, mixed thoroughly and allowed to stand for a period of 1 h.
- This mixture was then treated with 2 g of NaOH and dissolved in 50 ml distilled water and mixed thoroughly.
- The sand was treated with 10 ml of 1% of NH_4OH solution and 15 ml reducing agent (9% of sugar solution) mixed thoroughly as before and left for 1 h.
- The treated sand after solar drying was washed with distilled water to pH 7 and finally dried at 100–110 °C.

4.3.2 Activated Charcoal

Charcoal is a porous material which is often used to purify water, through the process of adsorption [5]. It is obtained by burning of wood. One of the prime reasons that activated charcoal behaves as an excellent filter material is its natural ability to remove many toxic substances from water, such as volatile organic compounds and chlorine. The steps employed for the preparation of activated charcoal are outlined below:

(a) Charcoal obtained by burning coconut shells is powdered.
(b) A 25% solution of (by weight) of calcium chloride is prepared, by weighing three parts of water and mixing in one part calcium chloride.
(c) Powdered charcoal is mixed with calcium chloride solution, and a paste is prepared.
(d) The paste is spread to dry and rinse with clean water.
(e) The paste is then baked at 225 °F for 30 min.

5 Model Fabrication

5.1 Modified Drawer Compacted Sand Filtration (MDCSF)

The Modified Drawer Compacted Sand Filtration (MDCSF) is a modified design for a conventional drawer compacted sand filter in which the sand layer is broken down into several layers of 10 cm height and placed in a movable drawer separated by 10 cm of air space from other layer. The new design for water treatment was based on two hypotheses: by placing the treatment media in movable drawers, separated by sufficient vertical distance, better oxygen access to the layers is facilitated, which improves the filter efficiency and facilitates maintenance requirements; the second hypothesis was that MDCSF can remove a high percentage of pollutants in STE with minimum space requirements.

This would allow such filters to be used even in locations where space is at a premium, such as dense urban areas. The comparatively lower maintenance requirements ensure that a wide range of users could easily operate the MDCSF. A laboratory-scaled model of MDCSF (Fig. 1), measuring 36 cm length $\times$ 27 cm width $\times$ 1.4 m depth with six drawers, was designed and operated. Table 2 describes the components of the MDCSF, along with their placement positions in the drawers.

Fig. 1 MDCSF drawers

Table 2 Configuration of MDCSF

Filter media	Specifications
Drawer 1	Aeration system
Drawer 2	Gravel; effective size 4.75 mm
Drawer 3	Sand; effective size 1.18 mm
Drawer 4	Charcoal; effective size 1.18 mm to 600 μm
Drawer 5	Silver-coated sand; effective size 600 μm
Drawer 6	Sand; effective size 75 μm along with collection system
Depth of media	10 cm for each drawer, 20 cm for last one
Perforation—for each drawer—expect the first and last one	Orifice size—4 mm second drawer 2 mm—third, fourth, and fifth Orifice spacing 2 cm

6 Results and Discussions

The water quality test parameters like total dissolved solids (TDS), BOD, COD, coliform test, phosphates, nitrates, and pH were tested by standard instruments and laboratory practices, as per IS 3025(53):2003. The properties of the synthetic septic tank effluent, prepared in the laboratory, were tested first, to ensure that it behaves in the same way as the actual septic tank effluent.

Table 3 shows the comparison between the parameters of the synthetic and actual STE. Most of the parameters for the synthetic STE prepared in the laboratory were found to match with the parameters requisite for the actual STE polluted water. For the treatment of STE polluted water, about 1 L of water was fed into the first drawer. This layer was aerated by the introduction of air bubbles beneath water in the drawer.

Water from the first drawer was taken out through a pipe, into the second drawer (gravel), and uniform distribution of water to this layer was ensured using a perforated acrylic plate of 4 mm thickness. Starting from this layer, a filter paper and a perforated

Table 3 Comparison of actual and synthetic STE

Parameters	Average STE polluted water concentration	Synthetic STE concentration
Total suspended solids (mg/l)	36–85	60
BOD_5 (mg/l)	118–189	137.28
pH	6.4–7.8	6.9
Faecal coliform (CFU/10)	10^6–10^7	6×10^6
Total dissolved solids (mg/l)	500–30,000	867
COD (mg/l)	500–900	600
Phosphate (mg/l)	5–20	6

Table 4 Comparison of water quality parameters for treated and contaminated water

Parameters	Concentration		
	Influent	Effluent	Pure water
Total suspended solids (mg/l)	60	nil	nil
BOD_5 (mg/l)	137.28	5.3	3–5
pH	6.9	7.6	6.5–8.5
Faecal coliform (CFU/10)	6×10^6	Absent	Absent
Total dissolved solids (mg/l)	867	560	500
COD (mg/l)	600	12	10
Phosphate (mg/l)	6	2	<0.3 mg/l

acrylic plate were placed below each drawer to ensure that the filter material, along with water, does not flow into the subsequent layers. An outlet is provided in the last drawer, from where the treated water was collected and tested. A contact period of 24 h was ensured. The test results for the treated water are given in Table 4. It is observed that the straining layers in the MDCSF are effective in removing the suspended solids from the contaminated water sample.

Further, the faecal coliforms were completely removed from the sample, after treatment. Overall, it can be seen that the while the existing design of drawer compacted sand filter performs reasonably well, the modifications are explained in the study, further making it even more effective, as shown in Table 4. The minor variations in some of the water quality parameters may be due to the inherent imperfections in the model and insufficient contact periods.

7 Economic Aspects

The cost of fabrication of a prototype of a MDCSF is given in Table 5. Since the prototype is developed for small-scale filtration purposes, the actual cost of a portable working household filter shall vary. However, it is to be underlined that filtration by this system proves to be much cheaper and efficient, compared to other existing

Table 5 Cost of setting up a domestic portable MDCSF

Item	Primary cost (INR)
Stand fabrication	1500
Drawers	1500
Silver-coated sand (1 kg)	500
Pipe fittings	200
Miscellaneous	300
Total	4000

filters. A major portion of the cost is related to the initial set-up of the drawer, pipe appurtenances, and the frame. The only recurring cost is towards the cleaning of the straining sand layers, after prolonged operation. Since the drawers are movable and there is sufficient air gap between them, maintenance is easier, compared to the conventional filters.

8 Advantages and Limitations of MDCSF

The filter helps in keeping the surrounding environment (particularly, surface and ground water) from the cross contamination. Since oxygen movement is facilitated due to natural and induced aeration, no anaerobic/toxic conditions are experienced and the problems of unpleasant odours are eliminated. The maintenance operations are easy, since it involves sliding out the drawer or mixing up the media and replacing the drawer back. The entire assembly is portable; hence, it is possible to replace the filter media in any layer by a suitable material as per requirement. Since the land foot print is very less (<1.5 m^2), the filter can be placed at the rooftop, backyard, or stairwell. The filter developed is considerably cheaper compared to the available alternatives and performs extremely well, as evident from the test results. A few limitations of the MDCSF are as follows.

Due to prolonged use, silver may leach out of the silver-impregnated sand layer, which can be understood from the discolouration of the filtered water (colour changes to light brown). Also, the use of silver nitrate to prepare the silver-impregnated sand layer increases the initial cost of set-up, which is, however, easily justified in the long run.

9 Conclusions

STE is one of the important contributors of ground water pollution. In order to minimize this pollution and to have pure water for drinking, domestic as well as for industrial purposes, it is essential that STE undergoes proper treatment before it is discharged to the soil or water. Drawer Compacted Sand Filter and Vetiver grass system are the conventional techniques employed to mitigate the problem. However, the treatments results are far from satisfactory. MDCSF is a novel approach for negotiating this problem. The modifications incorporated in the design involve the use of natural/forced aeration, the use of silver-impregnated sand layer, and an activated charcoal layer. The overall results of the treatment indicate that the STE after the treatment using MDCSF meets the drinking water standards, results in increased pathogenic removal as well as other parameters like BOD, COD, TDS, *E-coli.*, etc., to remarkable extent. The aeration system provided at the initial stage reduces the bacterial growth. Also, for obtaining a better result, the antimicrobial property of silver and absorption property of charcoal were utilized by the creation of silver-impregnated sand and activated charcoal.

References

1. Mittal, A. (2011). Biological wastewater treatment. *Water Today*.
2. Jefferson, B., Palmer, A., Jeffery, P., Stuetz, R., & Judd, S. (2004). Grey water characterization and its impact on the selection and operation of technologies for urban reuse. *Journal of Water Science and Technology, 50*(2), 157–164.
3. EPA. (2002). *Onsite wastewater treatment system manual*, EPA/625/R-00/08.
4. Henry, H. (1996). Treatment of septic tank effluent using puraflo peat biofiltration system. In *Proceedings of the Eleventh Annual on-Site Wastewater Treatment Conference Minimizing Impacts, Maximizing Resource Potential*
5. Mwabi, J. K., Mamba, B. B., & Momba, M. N. (2012). Removal of *Escherichia coli* and *Fecal Coli* forms from surface water and groundwater by household water treatment devices/systems. *International Journal of Environmental Research and Public Health, 9*(1), 139–170.

Heavy Metal Fractionation in Aerobic and Anaerobic Sewage Sludge

Sooraj Garg, M. Mansoor Ahammed, and Irshad Shaikh

Abstract The study assessed the speciation of heavy metals in sewage sludge. Sewage sludge samples were collected from three full-scale sewage treatment plants which employ different treatment processes. Sewage sludge samples from activated sludge process (ASP), UASB reactor (UASBR) and moving bed bioreactor (MBBR), and one anaerobically digested activated sludge (ASP-AD) was collected during different seasons of the year. Modified sequential extraction process was used classifying metals into acid-soluble/exchangeable fraction (F1), reducible fraction (F2), oxidizable fraction (F3) and residual fraction (F4). Five heavy metals, namely chromium, copper, mercury, lead and zinc, were analysed for different fractions. Among the heavy metals, Zn (1317–1448 mg/kg) and Cu (925–1196 mg/kg) contents were the highest, followed by Cr (129–151 mg/kg), Pb (60–86 mg/kg), and Hg (18–34 mg/kg). Concentrations of all heavy metals tested except mercury in MBBR were within the limits set by different agencies.

Keywords Anaerobic sludge · Heavy metals · Sewage sludge · Sequential extraction · Speciation

1 Introduction

With increasing number of municipal wastewater treatment plants in many countries, sewage sludge treatment/management has become a particularly important problem all over the world. Among the largest producers of sewage sludge include European Union and USA producing about 10 and 6.3 million tonne/year, respectively. Daily per capita sludge production varies in the range of 0.03–0.07 kg/capita/day in developing countries [1]. Contaminants like heavy metals, organic pollutants and pathogens in wastewater are concentrated in sewage sludge through wastewater treatment process, which threaten environment and human health.

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Land application is the most commonly used method all over the world for sewage sludge disposal and is being considered as one of the most economical ways for sludge disposal. This is because the sewage sludge represents a good source of nutrients such as nitrogen, phosphorus, potassium and other nutrients for agriculture reuse. However, the presence of toxic heavy metals in the sewage sludge greatly restricts its use as a fertilizer [2]. Heavy metal pollution affects the use of sewage sludge. Heavy metals such as Cu, Cd, Pb, Hg and Cr are found at relatively high concentrations in sewage sludge. The total heavy metal content of sewage sludge is about 0.5–2.0% (dry weight), and in some cases may be as high as 4% particularly for metals such as Cd, Cr, Cu, Pb, Ni and Zn [3].

The determination of total heavy metal content does not provide useful information about the risks of bioavailability, the capacity for remobilization and the behaviour of the metals in the environment [4]. It is necessary to distinguish their forms and assay their quantities. This may be achieved through speciation analysis. The most popular are chemical sequential extractions, which consist of treating a sample with chemical solutions of various leaching strength. For this, various extraction schemes (both single and sequential) were developed in the early 1980s, but most of them are modification of three-step extraction technique developed by Tessier and Rudd [5, 6].

A number of studies have been reported in the literature on the speciation of heavy metals in sewage sludge. However, very few studies compared the concentration of heavy metals in sludges from treatment plants using different treatment processes. Also, no studies have been reported from India on speciation of heavy metals in sewage sludge. The objective of this study was to assess the speciation of heavy metals in sewage sludge. Sewage sludge samples were collected from three full-scale sewage treatment plants which employ different treatment processes.

2 Materials and Methods

2.1 Sewage Sludge

For this study, sewage sludge was collected from three different treatment plants of Surat, India, which use different treatment technologies (Table 1). In Anjana sewage treatment plant, activated sludge process is used for treatment of wastewater. Sludge generated from primary settling tank and secondary settling tank is mixed and is anaerobically digested. The sludge cake after sun-drying is sold as fertiliser. In Bamroli sewage treatment plant, upflow anaerobic sludge blanket (UASB) reactor with extended aeration is used. Sewage sludge generated during the anaerobic treatment process is sent to the sludge drying bed for dewatering. In Khajod sewage treatment plant, moving bed bioreactor (MBBR) is adopted for the treatment, and the sludge generated from primary settling tank and secondary settling tank is anaerobically digested and then dried in drying bed which is sold for use in agriculture.

Table 1 Details of sludge collection points from sewage treatment plants

Wastewater treatment plant	Capacity (million litre per day)	Treatment process	Collection of sludge sample
Anjana Sewage Treatment Plant	82.50	Activated sludge process (ASP)	1. Raw activated sludge (ASP-Raw) 2. Anaerobically digested sludge (ASP-AD)
Bamroli-Vadod Sewage Treatment Plant	100	Upflow anaerobic sludge blanket (UASB) reactor with extended aeration process	1. UASB reactor sludge (UASBR)
Khajod Sewage Treatment Plant	25	Moving bed biofilm reactor (MBBR)	1. Raw MBBR sludge (MBBR)

Details of the sewage treatment plants are shown in Table 1. Sludge samples were collected monthly for four months from all the sampling points.

For analysis of physicochemical parameters, 1:10 (v/v) solution of sludge samples was mixed by a magnetic stirrer at 1000 rpm for 10 min. For extraction of heavy metals, the sludge samples were air-dried for 2–3 days and was ground in an electrical grinder and sieved through 212-μm sieve and stored at 4 °C in plastic pouches.

2.2 *Sequential Extraction of Heavy Metals in Sludge*

For the determination of heavy metal concentrations in sewage sludge samples, modified sequential extraction (modified BCR extraction) process was opted. During the extraction, metals were classified into acid-soluble/exchangeable fraction (F1), reducible fraction (F2), oxidizable fraction (F3) and residual fraction (F4) [7]. The detailed procedure is described as follows.

Step 1: Extraction of acid soluble/exchangeable fraction (F1): 0.5 g sludge sample was added in a 50-mL polypropylene centrifuge tube containing 20 mL of 0.11 mol/L acetic acid and was shaken for 16 h at room temperature. The solution and solid phases were separated by centrifugation at 4000 rpm for 20 min. Subsequently, the suspension was filtered through a 0.45-μm membrane filter and the solid residues were preserved for subsequent extractions.

Step 2: Reducible fraction (F2): The residues from Step 1 were shaken with a portion of 20 mL of 0.1 mol/L hydroxylammonium chloride (adjusted to pH 2 with nitric acid) for 16 h. The extraction procedure was the same as mentioned in Step 1.

Step 3: Oxidizable fraction (F3): The residues from Step 2 were dispersed in 5 mL of hydrogen peroxide (30%) and digested at room temperature for 1 h with

occasional shaking. A second 5-mL aliquot of hydrogen peroxide was introduced into and digested at 85 °C (water bath) for 1 h. The contents were evaporated to a small volume (1–2 mL). 25 mL ammonium acetate (1.0 M, adjusted to pH 2 with nitric acid) was added to the cool and moist residue. The sample was then shaken, centrifuged and the extract was separated as described in Step 1.
Step 4: Residual fraction (F4): 5 mL HNO_3 was added to the residues from Step 3. The contents were heated on a hot plate and evaporated to almost dryness. After cooling, the residues were dissolved in 5% (v/v) HNO_3. The resultant solutions obtained in different steps were subsequently used to determine the heavy metals.

A blank was also run at the same time. The concentrations of Cu, Cr, Hg, Pb and Zn in different fractions and in the resultant solutions obtained in Step 4 were determined by ICP-AES. Tests on each sample were conducted in triplicate, and the average value of results is reported.

2.3 Analysis

Total solids, pH, electrical conductivity, volatile solids, total Kjeldahl nitrogen (TKN), phosphorus (P) and faecal coliforms of sludge were determined as per standard methods [8]. Heavy metals (Cu, Zn, Pb, Cr and Hg) were analysed using ICP-AES (ARCOS Spectro, Germany).

3 Results and Discussion

3.1 Characteristics of Sludge

The mean values of physicochemical properties of sludge are presented in Table 2. The results show that the mean pH of sewage sludge ranged between 7.46 and 7.68 irrespective of treatment processes. Organic matter (measured as volatile solids) and nutrients (N and P) were high in sewage sludge irrespective of treatment process. Anaerobically digested sludge (ASP-AD) had a very low concentration of organic matter and low electrical conductivity. Total solid contents of raw activated sludge (ASP-Raw) and MBBR sludge were 19.91 and 18.52 g/L, respectively, while total solid content of UASBR sludge was 11.79 g/L. Sludge samples had moderate electrical conductivity that might increase the cation exchange capacity of soil on which this sludge will be applied. It was observed that for all sludge samples, there was high TKN, indicating that these sludge samples are rich source of nutrients which make them suitable for agriculture application [9]. High concentrations of organic matter (volatile solids) may lead the formation of humic acids in soil after its application on land which may decrease the pH of soil which indicates that pH of soil should be checked periodically after and before the application of sewage sludge