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Evaluating the Usage of Sand Filtration for Greywater Treatment

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ABSTRACT

The gap between water availability and demand is expanding worldwide over time. In Egypt, the water shortage has surpassed 40%, prompting the search for alternative sources to cover this deficit. Promoting sustainable water reuse and the reduction of the environmental impact of wastewater treatment are the main goals of finding a clean technology for greywater treatment. Evaluation process of a wastewater treatment system by conducting a physical pilot plant testing since performance under actual operating conditions needs to be evaluated; hence, optimization of the process can be made before full-scale implementation. Sand filtration process was applied to treat the collected wastewater from the university buildings and student dorms at the British university in Egypt. A depth filtration pilot plant of 110 litres was used with a fixed water head 80 cms. Experiments were conducted using the different filtrate flux rate and depths of sand filter media.. The optimum removal efficiency was achieved for a filtrate flux rate of 555 lit/m²/hrs and sand depth of 80 cms; values recorded were 78.65 and 80.03 % removal for chemical oxygen demand COD and total suspended solids TSS respectively.

1. Introduction

(Water is a vital natural and strategic economic resource essential for sustainable development, but climate change, population growth, water scarcity, and environmental degradation have increasingly hindered regional economic and social progress [1]. For Egypt, the River Nile is the main source of water that feeds the country with 55.5 billion cubic meters (BCM) per year. On the other side, the total needed water demand for Egypt is 114 BCM per year, to cover the different types of domestic, agricultural, industrial, and commercial uses. By calculating the

water footprint of Egypt, we found a gap of 58.5 BCM per year that need to be covered [2]. According to the 2021 update of the UN's Progress on Level of Water Stress report, three global regions face water stress levels exceeding 25%, with central and southern Asia experiencing high water stress and northern Africa facing critical stress [3].

Water Reuse is one of the alternative methods for water supply augmentation. It is a preferable method to compensate for the gap between water resources and demand rather than resorting to the desalination process due to the lower energy level consumption [4]. It is necessary to minimize the environmental

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impacts of contaminants of emerging concern to ensure the sustainability of water reuse [5]. Greywater refers usually to the wastewater generated from household or commercial buildings excluding its faecal contamination from the collected sewage flow. The separation process of domestic sewage into grey and black water offers a significant potential water source as greywater accounts of approximately 70% of the total domestic wastewater [6].

The characteristics of greywater are affected by household activity generation source, quality of water supply, age and structure of pipe network [7]. Greywater can be categorized according to its pollutant load into low pollutant load greywater (LGW), moderate pollutant load greywater (MGW), high pollutant load greywater (HGW), and mixed greywater. Among these, mixed greywater tends to have the highest level of contamination compared to other type [8]. Greywater contains a diverse range of contaminants, such as suspended and dissolved solids, acidic and alkaline substances, fats, oils, and grease. Additionally, pollutants like heavy metals, nitrates, phosphates, and xenobiotic compounds have also been identified in greywater [9]. Average concentration for certain parameters was previously recorded including a pH range of 7.2 to 8.0, total suspended solids (TSS) between 88 and 100 mg/l, and chemical oxygen demand (COD) varying between 370 and 806 mg/l [10]

The greywater treatment technologies commonly used are physical, chemical, and biological methods. Beyond conventional approaches, advanced technologies that have gained interest over recent years in greywater treatment include membrane-based filtration, enhanced electrocoagulation, nature-based solution approaches using constructed wetlands, and solar-powered treatment systems [11]. Filtration is based on the passing of fluids through porous media, thus removing the particles. In water treatment, especially for the treatment of greywater, one of the most effective ways is the filtration of sand. Sand filtration is widely preferred in greywater treatment as it is low in operating cost, simple to maintain, and highly effective in suspended solids and organic matter removal, thus is a sustainable and energy-conserving alternative to advanced membrane filtration or chemical treatment systems. During this procedure, as water permeates various strata of sand, larger particles become

ensnared through the process of physical filtration, whereas organic materials are decomposed by biofilms that form on the grains of sand [12]. This combined mechanism of both physical and biological filtration contributes to the high efficiency of sand filters.

Greywater, originating from domestic activities such as laundering, bathing, and dishwashing, can be efficiently processed through the use of sand filters. The straightforward nature, economic viability, and low maintenance requirements associated with sand filtration systems render them a favoured option for small-scale and decentralized treatment of greywater [13]. A designed sustainable multimedia filter succeeded in removing 60.8% to 100% of pH, turbidity, TSS, and COD respectively [14]. Studies show that sand filtration systems can remove between 70% and 95% of suspended solids and 50% to 70% of chemical oxygen demand (COD) in greywater [15]. Moreover, pathogen removal rates range from 60% to as high as 99%, depending on factors such as sand grain size and the flow rate of water through the filter [16]. The efficiency of sophisticated multi-layer sand filtering systems has improved. The systems can produce a significant decrease in microbiological pollutants and over 95% elimination of suspended particles when used in conjunction with other treatment methods. Thus, it is permissible to repurpose treated greywater for non-potable uses such as toilet flushing and irrigation [17]. Because of its efficiency and adaptability, sand filtration systems continue to be among the most fundamental components of sustainable greywater treatment technologies. The challenge in the evaluation and assessment of wastewater treatment is that technical, environmental, economic, and social parameters have to be weighed. Therefore, detailed research is a must for the evaluation of various technologies for wastewater treatment so that the most appropriate methods may be chosen in either developed or developing countries [18]. With the increasing number of wastewater treatment facilities, special emphasis is being given to early prediction and subsequent analysis of pollutant parameters by means of innovative methods [19].

Conventional sand filtering offers numerous advantages due to its low cost and minimal maintenance requirements. The straightforward installation and upkeep associated with this method

diminish the necessity for extensive sewage collection systems, thereby facilitating the repurposing of treated greywater for non-potable applications. However, a significant limitation of this approach is its tendency to become obstructed, and there are instances when the quality of the treated greywater may not consistently meet the required standards [20]. The segregation of domestic sewage into greywater and blackwater at the household level, along with on-site greywater treatment for possible reuse, is deemed both imperative and popular in many parts of the world. This study was, therefore, designed to investigate conventional sand filtration's effectiveness in the treatment of grey water. In addition, the study examines a pilot-scale model of a conventionally applied sand filtration system to determine the best operating parameters.

2. Material and Methods

2.1. Process Description

The sand filtration pilot plant was tested for different sand media depths and filter flux rates in order to determine the performance, and efficiency of the sand filtration pilot model during the filtration and backwashing stages. In this research, the greywater was used as collected from the British University in Egypt building sources and operated for nine runs, each run of a period of eight hours. The work plan during the experimental stage is indicated in Table (1). The sand filtration model was also tested for backwashing, this was done for the most optimum at an extended operation of eight hours. It was backwashed every six hours with treated water at a washing rate equal to five times the flux rate for a washing period of twenty minutes.

Table 1. Sand filtration work plan

Run	Flow Rate (lit/hrs)	Depth of filter media H (cm)	Operation period	Filtrate Flux rate (lit/m ² /hrs)
1	10	40	Each run (8hrs without washing)	555
2	25			1390
3	50			2780
4	10	60		555
5	25			1390
6	50			2780
7	10	80		555
8	25			1390
9	50			2780
BW	10	80	18 hrs	555

2.2. Collected Greywater Characteristics

The greywater used in this research was collected from the British university in Egypt. The collection process includes the university buildings and the student dorms. Special arrangements were made for the separation between grey and black collected wastewater. the collected greywater from different sources was mixed together before using it. The influent concentration of this study's specified parameters TSS, Total COD, and Soluble COD was measured, and then determined its average, minimum, and maximum values as shown in Table (2).

Table 2. Influent grey water characteristics.

	Total Suspended Solids TSS (mg/l)	Total Chemical Oxygen Demand tCOD (mg/l)	Soluble Chemical Oxygen Demand sCOD (mg/l)	pH value
Minimum Value	121	194	46	6.0
Average Value	185	325	105	7.25
Maximum Value	215	429	143	8.5

2.3. Sampling and analysis

The samples taken from the operation of this pilot plant are ten. One sample from the influent and nine samples from the effluent at a time interval of one hour for all runs except for the extended run with backwashing the effluent sample's time interval was two hours, and the volume of each sample taken was one liter. The analysis of influent and effluent greywater samples to determine the TSS, tCOD, and sCOD concentrations was done according to the standard methods for water and wastewater 23rd edition 2017 (method no. 2540 and 5220) [21]. Ph value was measured by pH-meter (Topac Consort C932) multi-channel analyzer. The calculation of the filtrate flow rate was determined using eq. (1)

$$J = \frac{Q}{A} = \frac{V}{A \cdot t} \quad \text{eq (1)}$$

Where:

- J Flux rate (lit/m²/hrs)
- Q Flow rate (lit/hr)
- A Surface area of the Filter (m²)
- V Volume (lit)
- t Time (hrs)

To ascertain the importance of the differences between the removal efficiencies of the different operational conditions, a statistical comparison was undertaken using t-tests to compare the mean values and assess whether differences in treatment efficacy were statistically different.

2.4. Sand filtration pilot plant

Greywater was collected from the British University in Egypt (BUE) and treated in a laboratory-scale sand filter unit. The model CE579 is

made by Gunt Hamburg, a filtration pilot plant composed of a number of tanks, valves, and a transparent polymethyl methacrylate (PMMA or Plexiglas) filter unit. The system is controlled by dedicated software integrated with a computer, as illustrated in Fig. 1. The sand filtration model encompasses filter and backwashing pumps that provide flow rates of up to 5.0 m³/h and 3.0 m³/h, respectively, at an average pressure of 1.5 bars. The EBCT was estimated using the bed volume; the filtration rate was found to be 2.16 minutes. The filter tower is a transparent PMMA Plexiglas tube with a height of 1660 mm, and inner and outer diameters of 150 mm and 200 mm, respectively. The piping system is connected to the soil filter by flanges at both ends, where PMMA flanges are glued onto the tube and PVC counter flanges are bolted in place using knurled screws. The seals at the joints are achieved with rubber sealing rings.

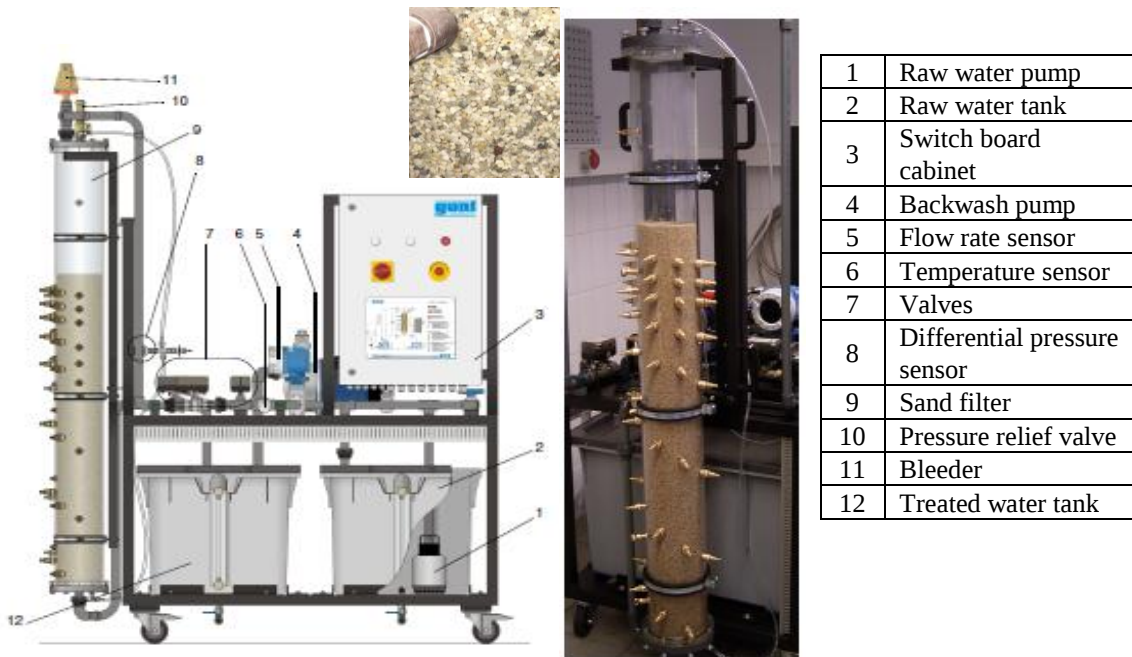


Fig. 1. Depth filtration pilot plant CE579

3. Results and Discussions

3.1. Flux rates effect on Removal efficiency

Three flux rates 555, 1390, and 2780 lit/m²/hr were tested with three different sand depths 40,60, and 80 cm. The water head was constant for all runs with a value of 80 cm and the sand effective size was 2.38 mm. Fig. 1, Fig.2, and Fig. 3 showed the different removal efficiencies recorded through different runs. It can be noted that the efficiency of TSS and total removal tCOD was decreased with the increase of flux rates and no removal for soluble sCOD was recorded.

The highest TSS and total COD removal rates were obtained at 555 liters/m²/h flux rate and 80-cm sand depth. Efficiencies of 81.08% and 78.75%, respectively, were observed in TSS and total COD. Influent TSS and total COD concentrations of 202 mg/L and 410 mg/L were reduced to 39.25 mg/L and 92.25 mg/L average effluent TSS and total COD concentrations, respectively. The system operated for 8 hours, but by the end, the filter passage dropped to 51.80%. The initial effluent values were higher than the Egyptian Standards; however, TSS decreased below the needed 50 mg/L within the first operating hour when the filter passage was 80.40%. For total COD, the effluent decreased below the standard value of 80 mg/L after four hours to filter passage of 59.20%. Other flux rates provided moderate removal efficiencies but made the filter clog faster, especially for greater depths of the sand.

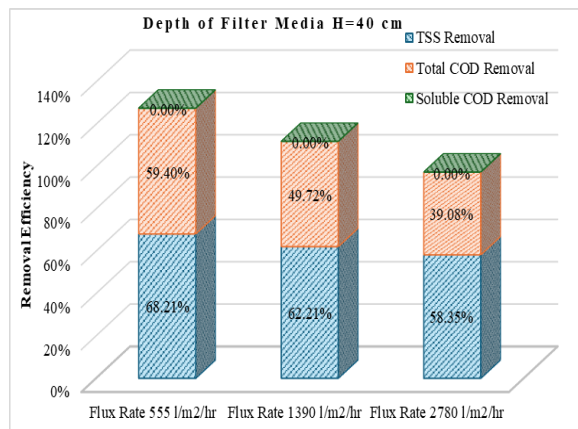


Fig. 2. tCOD, sCOD, and TSS removal efficiencies at different flux rates and depth of filter media 40 cm

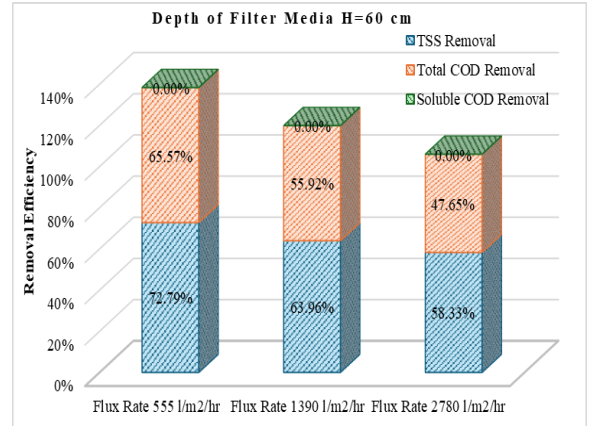


Fig. 3. tCOD, sCOD, and TSS removal efficiencies at different flux rates and depth of filter media 60 cm

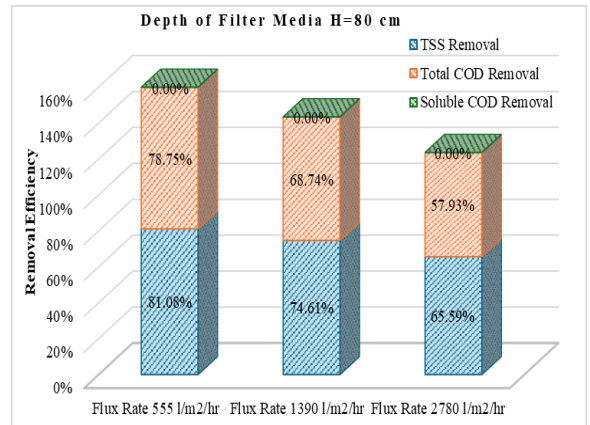


Fig. 4. tCOD, sCOD, and TSS removal efficiencies at different flux rates and depth of filter media 80 cm

3.2. Extended filtration with backwashing.

After determining the optimum flux rate of 555 lit/m²/hr and optimum sand filter media depth 80cm; a continuous run was operated for 18 hours with backwashing after 6 and 12 hours. The rate of backwashing was 2775 lit/m²/hr for 20 minutes by using filtered water. The results for the continuous run are shown in Fig. 5, Fig. 6, and Fig. 7.

In the long-term 18-hrs run with backwashing, average effluent TSS was about 39.75 mg/L, while the total COD was 90.06 mg/L, which corresponds to removal efficiencies of 80.03% for TSS and 78.65% for total COD, respectively. It can be induced from the data that effluent values are higher at the start of the run and decrease as filtration continues. From Fig. 7, it can be observed that the filter was operating at a net flux of 72.30% of the original 555 litres/m²/hr resulting in a net flux of 401.25 litres/m²/hr. This reduction in flux is owing to the clogging of filters and hence the overall productivity is affected.

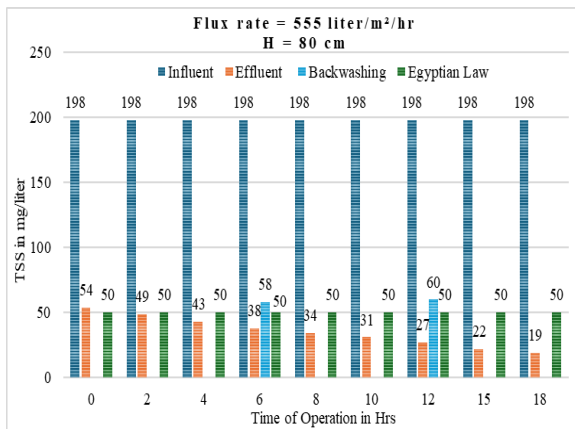


Fig. 5. TSS concentrations at Extended filtration run with backwashing

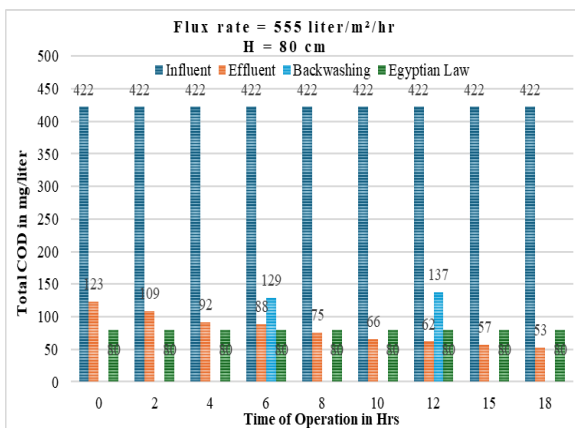


Fig. 6. Total COD concentrations at Extended filtration run with backwashing

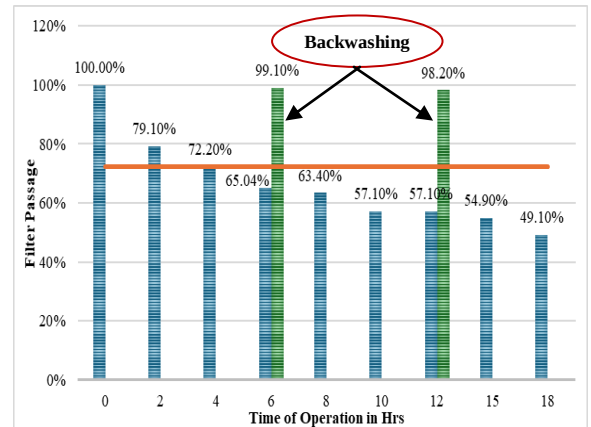


Fig. 7. Filter Percentage Passage at Extended filtration run with backwashing

4. Conclusion

Greywater separation, on-site treatment, and reuse for non-potable purposes such as toilet flushing and landscape irrigation are promising alternative sources of water. This can greatly help reduce the burden on natural water resources since greywater makes up approximately 65-75% of total household wastewater. The results from the pilot unit operation have indicated that lower flux rates and deeper sand media achieve better removal efficiency. However, increasing flux rates and media depth result in faster clogging of the filter. No significant removal efficiency for sCOD is achieved because sCOD refers to dissolved organic compounds that are small enough to pass through the filter media.

Grey water treatment helps achieve sustainability because fresh water is conserved, and this reduces environmental impacts due to the high consumption of energy it entails, while it also offers economic benefits as well as social benefits arising from water reuse. Conventional sand filtration is an alternative technology that can be adopted in both centralized and decentralized grey water treatment approaches. The technology is mature and environment-friendly, with low capital investment costs and operation costs.

Long-term pilot testing should be the focus of future studies to assess the long-term performance of sand filtration, establish a cost-benefit analysis to determine its economic feasibility, and examine other filter media that would provide greater removal efficiencies without the clogging issues.

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