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Evaluation of Sand Filter as a Non-conventional Post Treatment of Oil Refinery Wastewater: Effect of Flow Rate

Hossam F. Nassar[a*] and Mariam E. Fawzy[b,*]

[a] *Environmental Science and Industrial Development Department, Faculty of Postgraduate Studies for Advanced Sciences, Beni-Suef University, 62511 Beni-Suef, Egypt.*
[b]*Water Pollution Research Department, National Research Centre, P.Box 12622, Dokki, Giza, Egypt.*

Abstract

This work aims to evaluate the treatment efficiency and feasibility of a sand filter as a post treatment for a primary treated effluent from activated sludge process (ASP) of oil refinery wastewater (ORWW) at different flow rates. There are several factors influencing the treatment efficiency of the used sand filter including; wastewater characteristics, sand media and flow rates. The treatment unit consists of opaque sand filter column fabricated from PVC material. It was fed by a primary treated effluent from ASP of ORWW. The average concentrations of raw ORWW for turbidity, Chemical oxygen demand (COD), Biological oxygen demand (BOD), Total suspended solids (TSS) and phenol were 419 NTU, 409 mgO_2/L, 118 mgO_2/L, 111 mg/L and 2 mg/L, respectively. The sand filter was operated at three different flow rates; 120 L/h, 240 L/h and 360 L/h. The experimental results proved that 240 L/h is the optimum flow rate. The achieved removal values at this flow rate were 79.04%, 55.82% and 63.55 for turbidity, COD and TSS, respectively. The treated permeate complies with the National Regulatory Standards for irrigation and/or safe discharge on water streams after slight disinfection.

Keywords: Activated sludge process; flow rates; oil refinery wastewater; post treatment; reuse; sand filter.

1. Introduction

The worldwide freshwater resources are limited and the scarcity of such resources is underway in a few years. In Egypt and other developing countries, the growing urbanization and industrialization in many regions resulted in a significant increase in the generated amounts of wastewater **[1]**. The disposal of wastewater with insufficient treatment to water streams is one of the most serious environmental problems, leading to contamination of water resources and consequently affects humans, animals, and plants. Adequate environmental protection is a fundamental right for all living creatures **[2- 3]**. Considering the growing needs of the country for freshwater, it is important to preserve and rationalize the current water resources. Petroleum refinery effluent (PRE) consumes large amounts of wastewater which poses an environmental risk to aquatic creatures if they are discharged without treatment. They are generated from manufacturing fuels, petrochemical, lubricant intermediates and crude oil refining processes **[4]**. Oil refining wastewater is polluted with hydrocarbons, phenols, suspended matter, dissolved solids, minerals and a mixture of oils **[5]**. The utilization of treated effluent in recycling and /or reuse is a great approach. However, the treated effluent of oil refinery remains a challenging task for reuse in recycling; such as injection walls for crude oil exploitation enhancement, steam boilers, cooling water. Otherwise, the reuse of treated wastewater for higher priority uses as irrigation provides a logic answer to the problem that has been adopted by many countries **[6]**. In order to solve the problem, different treatment methods such as biological aerated filter, multi-stage roughing fine filtration system after packed anaerobic sludge blanket have been used for the purification of wastewater before its reuse **[7-9]**. According to the Strategic plan 2030 of Egypt, the reuse of treated wastewater in irrigated agriculture is becoming a common practice **[10-1]**. Regarding the stringent water quality requirements for reuse, sand filter systems provides adequate wastewater treatment efficiency mostly as

*Corresponding authors E-mail addresses:hossamnassarnrc@gmail.com ; (Hossam F.Nassar).
mariamemadeldin@hotmail.com ; (Mariam E.Fawzy).
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post treatment systems **[11]**. Sand filtration is a simple technology that has been used for over 200 years in water and wastewater treatment as a particle and pathogen filter **[7]**. It act on removing dirt and substantial particles from wastewater thus improving the effectiveness of water quality and disinfection property as well of treated water for beneficial reuse. These systems have been used widely all over the world as on-site wastewater treatment for small and urban communities **[12]** as it enhances the removal of non-biodegradable constituents from wastewater **[5]**. The main advantages cited for sand filters refer to its ease of operation, feasibility to assemble and simplicity of maintenance. This system has no need for energy, chemicals or land area to install compared to other natural systems because of high hydraulic loading rates. In sand filtration, the treatment efficiency is related to the depth of the sand layer because sand particles can provide a large surface for biofilm formation and consequently enhancing the biological activity. The biological activity of the sand filter may act on creating suitable conditions for the biodegradation and/or mineralization of organic pollutants **[13]**. Previous studies proved the effectiveness of sand filters for wastewater treatment at both laboratory and pilot scales, and their ability for improving the water quality parameters such as chemical oxygen demand (COD), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), phosphorus (P), turbidity, total coliforms and others **[10,8,14]**. Farooq and Al-Yousef **[15]** studied the use of sand filters with effective sand sizes of 0.31 and 0.56 mm as a post treatment after the secondary chlorinated effluents. They achieved COD removal of 50-67% and 90% removal of total bacterial counts. The sand filters have multiple variables and have been conventionally designed on hydraulic loadings and organic loading rates. Sand filters aids in the purification of wastewater by the dual action of staining and microbiological processes. Abou-Elela et al. **[10]** used a multistage sand roughing fine filtration unit (MSRFF) as a post treatment for municipal wastewater unit to improve the quality of packed bed up flow anaerobic sludge blanket (P-UASB) amenable for reuse. They achieve a quality of effluent with complete removal of Fecal Coliforms with residual concentrations of TSS, COD and BOD of 10.9 mg/L, 60 and 34 mgO_2/L, respectively. Recently, sand filters are implemented focusing only on the sand size as a controlling parameter without studying the effect of flow rates on wastewater treatment process. Therefore, the main objective of the present work is to: (i) evaluate the feasibility and treatment efficiency of on-site sand filter technology as a post treatment of oil refinery wastewater (ORWW) (ii) Study the effect of flow rates for improving the quality of effluent. (iii) Assess the suitability of the treated ORWW effluent for release into the water body and complying with the National Standards of water reuse.

Materials and Methods

2.1. Collection and wastewater characterization

Laboratory-activated sludge system, treating oil refinery wastewater was operated at ambient room temperature (23 ± 2 °C). The biologically treated effluent was collected in a plastic tank with a capacity of 200 L. It was continuously stirred slowly to maintain homogeneity and solids in suspension and fed to a sand filtration unit at different flow rates. The system was operated for three months continuously and 30 samples were collected from treated wastewater on the basis of 10 samples for each flow rate. The characterization of ORWW and biologically treated effluent are shown in Table (1).

Table 1 Characterization of ORWW and biologically treated effluent

Parameters	**Unit**	**ORWW**	**Primary treated effluent**
pH	--	7.66	7.6
Turbidity	NTU	416	4.2
TDS	mg/L	14320	11400
COD	mgO_2/L	409	55
BOD	mgO_2/L	118	10
TSS	mg/L	111	7.6
TKN	mgN/L	54.8	22.4
NH_3-N	mgN/L	33.2	12.32
TP	mgP/L	2.22	3.8
Oil & Grease	mg/L	70.6	4
Phenol	mg/L	2	N.D*
E.Coli	CFU*/100 ml	$4.7x10^6$	$3.4 x10^4$

** N.D: Not Detected*
***Average of 12 samples*

2.2. Experimental Set-up

A fabricated sand filter is made of opaque PVC columns, its height is about 130 cm, 10 cm internal diameter and consequently the column has an effective volume of 9400 cm^3. The column was filled with a three layers sequenced as follows; 8 cm of gravel on the top followed by 60 cm of sand in the middle as an active layer and finally 8 cm of gravel at the bottom of the filter, this is to enhance the uniformity of water flow. Fig. 1 shows a schematic diagram of the sand filter. Sand and gravels were washed carefully with distilled water before filling into the column to remove clay, minerals, dirt and other contaminants. Different sizes of gravel were mixed ranged from 3-1 mm and the effective size of sand ranging from 0.2-1.4 mm.

The uniformity coefficient (UC=D60/D10) is 1.53. The recommended uniformity coefficient of 0.6 – 0.9 m filter depth is UC < 3 that matches with the conditions of our experiment **[16]**.

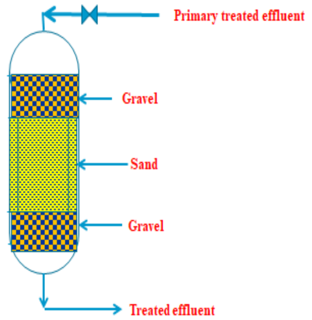

Fig.1. Schematic diagram of sand filter column

2.3. Analytical Methods

The mineralogical characteristics of the sand were examined by X-ray diffract-meter (XRD) using X'pert High Score PANalytical with mono-chromated CuKα radiation operating at 45kV/40mA. The obtained data from XRD were all collected at the same experimental conditions, in the angular range of 3°≤ 2 ≤ 90° and scan rate of 1°/min at ambient temperature. The X-ray fluorescence determined the compositions of the main chemical elements of the sand. Physico-chemical parameters including pH, turbidity, total dissolved solids (TDS), COD, BOD, TSS, TKN, TP, Oil & grease and Phenol were assayed as described in the Standard Methods for the Examination of Water and Wastewater **[17]** for raw wastewater as well as treated effluents. Also, bacteriological examinations including E.coli was investigated according to Engelbrecht, **[18]**.

2. Results and Discussion

2.1. Sand Characterization

A medium to coarse sand with an effective size between 0.2 and 1.4 mm is the ideal size for sand reactors. The textural classification the of Soltner and granulometric analysis showed that the used sand were in average grain sized **[19]**. The sand uniformity coefficient has to be less than 4.0 to show good hydraulic conductivity and to reduce the risk of clogging **[20]**. The characteristics and mineralogical composition of the used sand in this study can be shown from the diffractogram obtained from the (XRD). Fig. 2 shows the analysis of X-ray powder diffraction represents sand composition contains dolomite, calcite and quartz. The relatively high composition percentage of CaO and MgO could be interpreted by the high contents of dolomite (26.4%). Table 2 shows the elemental analysis using X ray diffraction analysis that indicates the main elements corresponding to the major proportion of SiO_2 because of the high content of quartz (59.4 wt %) of the used sand **[21]**.

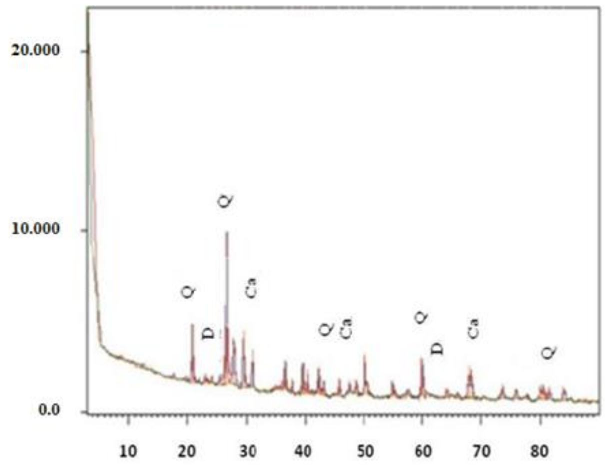

Fig.2. X-ray Diffractogram of the used sand, (Q: quartz; D: Dolomite; Ca: Calcite)

Table 2. X-ray Fluorescence Analysis of the used Sand

Oxides	**(Wt %)**
SiO_2	59.4
CaO	12.2
Al_2O_3	8.7
MgO	4.1
Fe_2O_3	2.8
K_2O	1.1
Na_2O	0.88
SO_3	0.51
P_2O_5	0.27

2.2. Performance of sand filter

The quality of treated effluent after sand filtration process operated at different flow rates of 120, 240 1nd 360 L/h was evaluated in terms of the removal efficiency of pollution parameters such as turbidity, organic matter, TSS, TKN, TP, and E.coli to comply with the National standards and regulations for wastewater reuse **[22].**

3.2.1 Turbidity and TSS removal at different flow rates

The mode of operation of sand filter either continuous or intermittent affect the turbidity removal rates. It has been investigated that the continuous mode as in this study offers better removal rates also as the depth of the sand increases the removal efficiency increases **[23]**. Fig. (3) shows the effect of flow rate on turbidity removal. The average residual values were 1.45, 0.88 and 1.61 NTU at 120, 240 and 360 L/h, respectively, thus less than the required regulation limits. TSS residual concentrations at different flow rates are represented in Fig. 4. The TSS concentration in the primary treated effluent using ASP ranged from 12.5 to 5 mg/L with an average value of 7.5 mg/L. The obtained removal efficiencies of TSS after sand filter were 53.94%, 63.55 and 50.65%, at a flow rate of 120 L/h, 240 L/h and 360 L/h, respectively. The achieved TSS removal rates ranged between 96.62% - 97.5% were better than achieved by Tyagi et al. **[24]** as they obtained almost 89.1% at 140 L/h filtration rate. Also, the achieved TSS removal values were significantly higher than those obtained by Nakhla and Farooq **[11]**. It is obvious that the best removal rates for turbidity and TSS achieved at a flow rate of 240 L/h. The obtained effluent were in compliance with the Egyptian Code of Practice for treated wastewater reuse in irrigation and meets the effluent TSS limit for irrigation **[25, 26]**. The high removal efficiency of TSS of the studied system could be attributed to the porosity and physico-chemical properties of sand **[27]**. Moreover, the straining property of sand media strongly contributes to TSS removal mechanism, where-by the larger sand particles than the pore space of the used sand filtering media are mechanically strained out. These results can be interpreted by the dominant forces of the electrical interactions between charged media surface and the charged particles that can control the attachment mechanism between particles **[28]**. Some other mechanisms may also exist including impaction, adhesion and interception. These coexist mechanisms have a smaller effects and mostly masked by the effect of straining action. The removal of the fine particles can be achieved by two main steps: transport and attachment. In which the particles are transporting to the surface where they can be easily removed by one or more of the operative removal mechanisms **[27]**. It is also clear from the results that, as the turbidity and total suspended solids decrease, the total dissolved solids tends to decrease due to the adsorption of ions on sand particles.

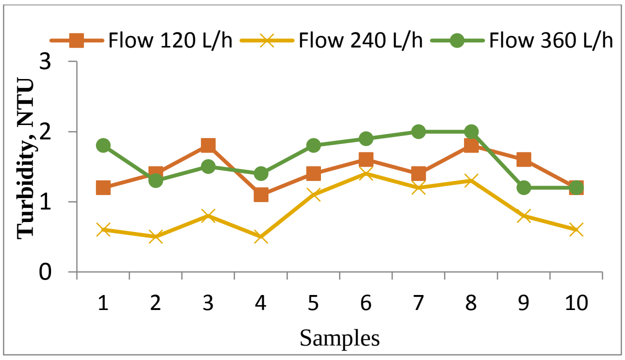

Fig.3. Effect of flow rate on Turbidity

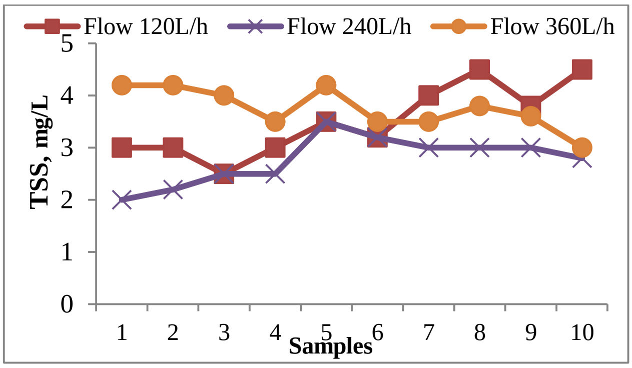

Fig. 4. Effect of flow rate on TSS

3.2.2 Organic Matter Removal

The effect of different flow rates on COD removal is shown in Fig. 5. It is known that COD is the most important indicator of organic load in wastewater. The organic removal depends mainly on the flow rate. Where, as the flow rate increase the COD removal efficiency decrease. For the sand filter, after the start-up period the treatment efficiency reached the peak values and remained steady. The achieved average COD percentage removal at different flow rates of 120 L/h, 240 L/h and 360 L/h were 47.45%, 55.82% and 45.64% respectively. The best removal values of 55.82 % COD were achieved at hydraulic rate 240 L/h with a residual value ranged from 21-26 mg O_2/L. It was quite clear here that in all the experimental runs the residual concentration of BOD is less than 5 mgO_2/L and this is attributed to the presence of inhibitors such as phenol in ORWW. The interpretation of reduction of COD and consequently BOD values may be due to the further filtration of suspended solids and the maturation of biological layer in the sand media as well as the established purifying bacteria which fasten the processes of wastewater purification through biodegradation, mineralization, biotransformation and nutrient assimilation **[29, 30]**. The achieved removal efficiency of COD using the studied sand filter is significantly better than that reported by Amin et al. **[31]** of 50% of organic removals. Moreover, 94.05% of organic removal from wastewater have been achieved which is better by 10% achieved by Prochaska et al. **[32]**.

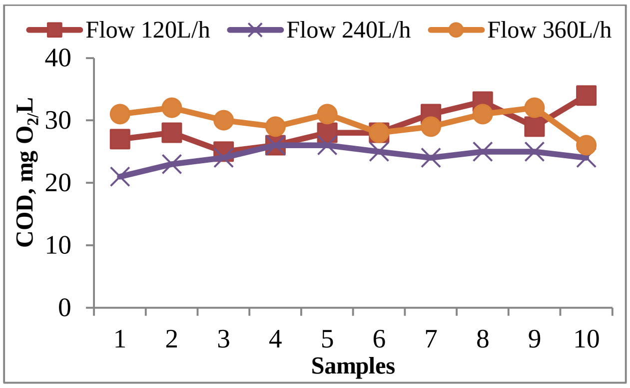

Fig. 5. Effect of flow rate on COD

3.2.3. Nutrient Removal

One of the most important evaluating parameters of sand filter efficiency is the ability for the removal of Total Kjeldahl Nitrogen (TKN) concentrations. The removal percentage of TKN, ammonia nitrogen and phosphorous for the used sand filter is shown in Fig. 6. The concentration of TKN, ammonia nitrogen and phosphorous in the biologically treated effluent has an average value of 22.4 mNg/L, 12.32 mNg/L and 3.8 mgP/L, respectively. Whereas, the obtained removal values of TKN after sand filtration at 120, 240 and 360 L/h flow rate were 77.67%, 69.64% and 59.82%, respectively. The removal of TKN could be explained by the presence of nitrifying microorganisms that are dominant in sand filter. These microorganisms are responsible for successive nitrification and denitrification process. It is clear from the result that as the flow rate decreases the percentage removal of TKN increases. This could be interpreted by the fact that for lower flow rate values, the longer contact time, and hence the greater interaction between sand filter and nitrogen. In addition to the presence of fine sand particles that provides a high specific surface area for biomass formation **[23]**. The achieved TKN removal values for our used sand filter in this study are significantly higher than those reported by Liu et al. **[23]**. The obtained results indicated that the ammonia nitrogen content in the final effluent was decreased after their passage through the used sand filter at different flow rates. Therefore, the achieved removal values of TKN confirmed that the efficiency of the used sand filter at a flow rate of 120 L/h was better than other flow rates of 240 L/h and 360 L/h. The average removal values for ammonia nitrogen (NH4-N) were 82.3%, 73% and 55% respectively at a flow rate of 120 L/h, 240 L/h and 360 L/h at the end of the filter run. In the case of 120 L/h, the interpretation of the high percentage of ammonia nitrogen removal may be attributed to the intense mineralization followed by possible nitrification process resulted in significant ammonia nitrogen removal that support the assumption reported by Bastviken et al. **[34]**. However, all these results confirmed the removal effectiveness of ammonia nitrogen through the applied sand filter and were in agreement with **[29-30]**.

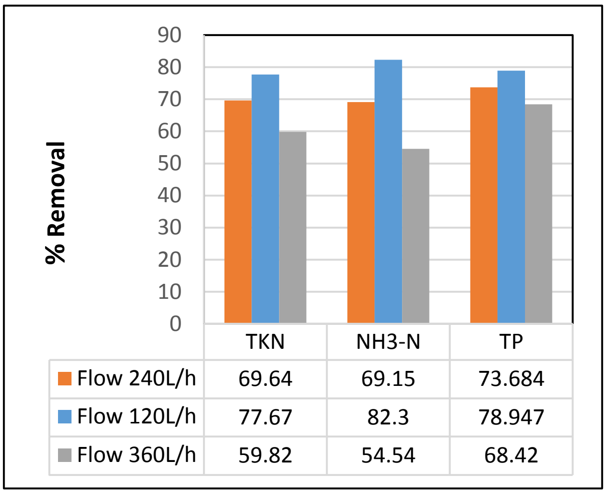

Fig.6. Effect of flow rates on nutrients removal

As shown in Fig. (6) phosphorus removal at the different operational runs have the same trend like nitrogen removal. The average percentage removal efficiency at 120 L/h, 240 L/h and 360 L/h was 78.94%, 73.68% and 68.42%, respectively. The treated effluent from the applied sand filer have a great concern because the high TP content may affect the eutrophication process in surface fresh water and consequently affect water resources. To explain the TP removal efficiency throughout the sand filtration, there are different mechanisms by which phosphorus compounds can be eliminated from wastewater including adsorption, absorption and ionic exchange **[35, 32, 36]**. The achieved results in this study indicated that the best removal efficiencies of TP were obtained at a flow rate of 120 L/h.

2.3. Overall efficiency of sand filter

The results presented in Table (3) shows the overall efficiency for the sand filter as a post treatment for ORWW. It is worth to note that E.coli was decreased by 2 logs after sand filtration and this is attributed to the fact that, as the organic content decreases, the microbial load decreases due to the depletion of nutritive substrate [37]. Hence, the overall quality of the treated effluent at the three operational flow rates namely; 120, 240 and 360 L/h is in compliance with the ECP (501/2015) for the use of treated wastewater for agricultural purposes**.**

Table 3 Overall efficiency of sand filter at different flow rates

Parameters	Unit	Flow Rate (L/h)			Compliance with ECP (501/2015)
		120	240	360	
pH	--	7.8	7.84	7.65	--
Turbidity	NTU	1.45	0.88	1.61	√
COD	mgO_2/L	28.9	24.3	29.9	--
BOD	mgO_2/L	<5	<5	<5	√
TSS	mg/L	3.5	2.77	3.75	√
TKN	mgN/L	5	6.8	9	--
NH_3-N	mgN/L	2.18	3.8	5.6	--
TP	mgP/L	0.8	1	1.2	--
Oil & Grease	mg/L	N.D	N.D	N.D	--
Phenol	mg/L	N.D	N.D	N.D	--
E.Coli	CFU/100 ml	1.3×10^2	1×10^2	1.2×10^2	√

**Average values of 10 samples for each experimental run. **N.D: Not detected*

7. Conclusion

The main objective of the present study is to highlight the effect of flow rates on the efficiency of sand filtration as a post treatment for pre-treated oil refinery wastewater. As a result, the following conclusions were obtained:

- The sand filter removal efficiency was strongly affected by the applied flow rates. Where by the flow rate increases the removal efficiencies decreases to some degree.
- The optimum flow rate was 240 L/h where the best removal efficiency in terms of turbidity, COD, TSS, TKN, NH_4-N, phosphorous, oil & grease and E.coli were 79.04 %, 55.82 %, 63.55 %, 69.64 %, 69.15%, 73.68 % and 2 logs of E.coli.
- The achieved effluent quality from the applied sand filter is in compliance with the U.S. EPA standards of water reuse.
- Utilization of the treated effluent of ORWW using sand filtration process can be achieved after determining the optimum operating conditions. The treated effluent can be used in other purposes rather than reclamation/ treatment such as cooling water, injection walls for crude oil exploitation enhancement and steam boilers.

8. Conflicts of interest

“There are no conflicts to declare”.

9. References

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