Slow sand filtration as a tertiary treatment for the secondary effluent from sewage treatment plant

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Abstract

A field-pilot scale slow sand filter (SSF) was constructed at Al-Rustamiya Sewage Treatment Plant (STP) in Baghdad city to investigate the removal efficiency in terms of Biochemical Oxygen Demand (BOD_5), Chemical oxygen demand (*COD*), Total Suspended Solids (*TSS*) and Chloride concentrations for achieving better secondary effluent quality from this treatment plant. The SSF was designed at a 0.2 m/h filtration rate with filter area 1 m^2 and total filter depth of 2.3 m. A filter sand media 0.35 mm in size and 1 m depth was supported by 0.2 m layer of gravel of size 5 mm. The secondary effluent from Al-Rustamiya STP was used as the influent to the slow sand filter. The results showed that the removal of BOD_5, COD, TSS, and Chloride were 73.84%, 73.01%, 63.71% and 49.80%, respectively after 28 days of the SSF operation. The overall removal efficiency of Al-Rustamiya STP has been improved by this tertiary treatment reaching to 91.15% for BOD, 86.84% for COD, 86.55% for TSS, and 59.50% for chloride which indicated that the final effluent became acceptable to the Iraqi regulations for disposal.

Keywords: Safety irrigation, Sand bed depth, Secondary effluent, Slow sand filtration, Tertiary treatment, Wastewater stabilization.

1. INTRODUCTION

The disposal of sewage effluents into water bodies may cause danger to the receiving environment by high pollutant loads such as Biochemical Oxygen Demand (*BOD_5*), Chemical oxygen demand (*COD*), nutrients as nitrogen (*N*) and phosphorous (*P*) and bacterial load. Tertiary treatment can improve the quality of secondary effluents to reach disposal standards which can be discharged into water bodies or be re-used for irrigation. Many researchers have worked to improve the secondary effluents from sewage treatment plants using slow sand filters as tertiary treatment procedures. The slow sand filters of effective size 0.29 mm and depth of 0.97 m could reduce suspended solids by 88%, BOD_5 76%, bacteria count 99.9 % and coliform bacteria by 97% [4, 6].

The ability of slow sand filters using granular media like anthracite coal with sand media was investigated by several researchers [7, 9, 11] to remove suspended particles within 70%, volatile soluble solids 56% and COD removal reached 38%, and pathogenic viruses and bacteria in this process was also efficiently removed. They also achieved simultaneous nitrification–denitrification processes in these filters.

The rapid sand filters were evaluated in three tertiary sewage treatment plants in the State of Kuwait which found the yearly reductions of SS, VSS, BOD, and COD were determined in each plant with 95% and 99% significant levels achieving water quality standards for irrigation [8]. Some researchers were examined the filter performance through the operation of stratified sand filters using a synthetic influent resembling high-strength dairy wastewater. Results showed the removal of COD and TSS that were greater than 99% and total nitrogen reduction reached 86% [10].

The performance of low-pressure membranes (MF/UF) in wastewater reclamation using slow sand filters as a pre-treatment was tested. A pilot-scale-SSF was constructed to treat secondary effluents for the removal of biopolymers which are considered the major dissolved organic foulants. High removal of biopolymers was achieved in this study at temperatures higher than 15 °C, with concentrations lower than 0.5 mg C/L and with sufficient oxygen levels [13].

The secondary effluents from Al-Rustamiya South Station are causing sever pollution problems when discharged into Diyala River as they are out of the Iraqi effluent disposal regulations. So, this study aims to performance the slow sand filter with field-pilot scale as a tertiary treatment process for treating the secondary effluent from this plant.

2. MATERIALS AND METHODS

2.1 Study Area Description

Baghdad city is about 900 km^2 in its area with an approximated population of eight million capita in year 2016 approximately. All data below were collected from Baghdad Mayoralty and Al-Rustamiya STP office, Baghdad city has three sewage treatment plants, Al-Rustamiya South Station, Al-Rustamiya North Station and Al-Karkh. Al-Rustamiya STPs are the largest projects serving Al-Rusafa district (eastern side of Baghdad). The plant effluents are discharged into Diyala river and then to Tigris River, as shown in Fig. 1 (a and b). These plants suffer in recent years of weakness in performance due to the late arrival of spare parts for maintenance of the mechanical and electrical equipment.

a) Al-Rustamiya North NTP.

b) Al-Rustamiya South STP.

Fig. 1 Study area location of Al-Rustamiya north and south STPs (Google earth).

The treatment process in Al-Rustamiya STPs is done by two stages, the primary stage for the removal of inorganic matter and the secondary (biological) stage for the decomposition of the organic matter. Al-Rustamiya project consists of:

a) The old project, Al-Rustamiya South STP working since 1963 to serve 1,500,000 inhabitants in the eastern side of Baghdad and consists of Zero (F0) and Expansion I (F1) projects, with a designed capacity of 175000 m^3/day while the actual capacity reaching the plant is 300,000 m^3/day.

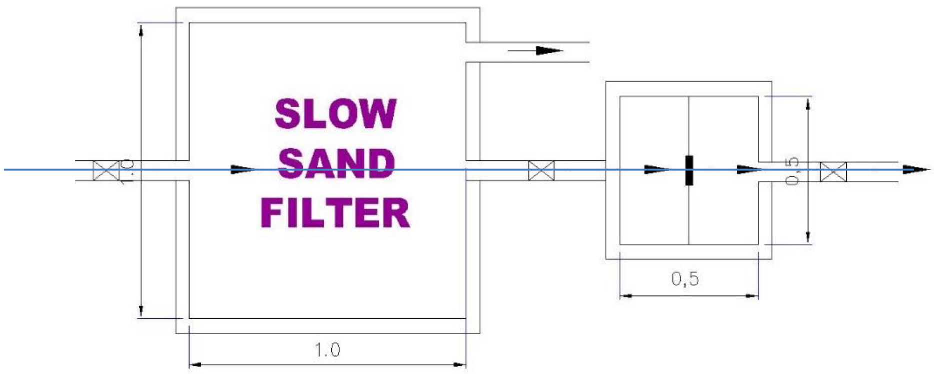
b) Al-Rustamiya North STP serves 1,500,000 capita; Expansion II (F2) project working since 1984 with a design capacity of 300,000 m^3/day and the actual capacity reaches to 450,000 m^3/day.

2.2 Field-pilot Scale Slow Sand Filter

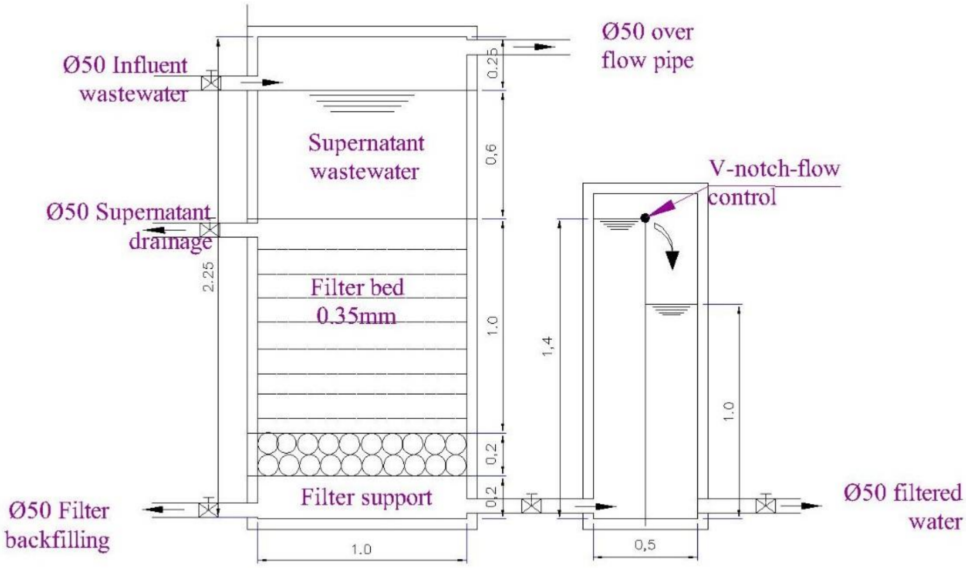
A field-pilot scale slow sand filter (SSF) was constructed at Al-Rustamiya STP to investigate the removal efficiency in terms of BOD_5, COD, TSS, and Chloride concentration for achieving better effluent quality from this treatment plant. The field-pilot plant operated continuously since April to June 2016 to filtrate the secondary effluents from this plant. The SSF was designed with a filtration area of 1 m^2 and total filter depth of 2.3 m. The filter bed is 1 m in depth with a graded sand media of effective size 0.35 mm with uniformity coefficient (UC) 2.5 and supported by 0.2 m layer of gravel (5 mm in size). The underdrain system consisted of perforated UPVC pipes (100 mm in diameter) which are placed in parallel lines. A uniform and steady treated sewage influent to filter was maintained by using an overflow weir. Fig. 2 (a and b) shows the pilot scale plan and section of the slow sand filter (SSF). The filter was operated with a filtration rate of 0.2 m/h and 10 m^3/day flow rate in a down flow mode. The filter media head loss was increased as the filter became clogged; due to the buildup of suspended solids in the media pores hence washing the filter is necessary. The filter was washed by draining the water under the sand bed to a depth of 0.10-0.20 m below the top surface of the sand. This layer becomes relatively dry and easy to handle. About 2-5 cm of this sand layer is removed manually from time to time and new sand is added to reduce the head loss.

2.3 Samples and data collection

The sewage used in this study was the secondary effluent from Al-Rustamiya STP which was directly feed into SSF pilot plant (Fig. 2). The influent and effluent daily samples were collected and analyzed for BOD_5, COD, TSS, pH, and Chloride concentrations to determine the performance of this filter during the period from April to June 2016. Table 1 and 2 show the results of the laboratory analyses that were performed by Al-Rustamiya STP Office-Mayoralty of Baghdad. The procedures described by Standard methods for the examination of water and wastewater were carried out in all of the experimental analysis [2].



a) Plan



a) Cross Section A-A

Fig. 2 Diagram of the pilot scale-SSF, a) plan and b) section.

3. SLOW SAND FILTRATION CONCEPT

The basic concept in slow sand filtration is that the influent flows through a porous media (0.15 to 0.35 mm in diameter) at low filtration rates. In treating wastewater this procedure will help for the growth of a biological population and inert deposits within the sand bed, this is known as the schmutzdecke layer. Under normal operation conditions, about 10 days are required for the development of the schmutzdecke layer on the bed surface. The effectiveness of slow sand filters for BOD and COD removal is dependent upon the development of this layer [5]. The schmutzdecke layer is removed about 2-5 cm from the top layer of the sand bed during washing (after the filter is drained) then sand replacement is necessary. The sand layer scraping interval depends on the treated sewage impurities and the hydraulic loading rate applied to the filter. Sand replacement provides a complete exchange of porous media over time and prevents any accumulation of silt that could clog the sand bed [4].

4. RESULTS AND DISCUSSION

4.1 Raw sewage characteristics

Tables 1, 2 and Figs. 3 to 6 show the minimum, maximum, and average values of influent sewage characteristics to Al-Rustamiya STP (indicated as C). The BOD_5, COD, TSS, and chloride varied from 160 to 300, 255 to 861, 75 to 456, and 240 to 380 mg/L, respectively, where the pH value ranged from 7.08 to 7.41. The biodegradability (BOD_5/COD) ratio varied from 0.35 to 0.97 with an average ratio of 0.62 which indicates that this sewage can be treated biologically as shown in Table 3 [12].

4.2 Performance of the secondary stage in the treatment station

Table 1, 2 and Figs. 3 to 6 also show the characteristics of the minimum, maximum, and average values of the effluent after secondary treatment from Al-Rustamiya STP (indicated as F2). The BOD_5, COD, TSS, and chloride average concentrations were 79.97, 155.74, 81.80, and 269.71 mg/L respectively, with pH value 7.46. The removal efficiency of BOD_5, COD, TSS, and chloride were 65.40%, 61.54%, 63.53%, and 19.32%, respectively. This stage was limited and the quality of the effluent was not within the local Iraqi regulations for disposal (as shown in Table 1). The biodegradability of the treated sewage (BOD_5/COD) varied from 0.31 to 0.87 with an average ratio of 0.56 this indicates that more treatment is required and this effluent did not confirm with the typical ratios of the treated sewage [1]. By observation the biological treatment in the plant is not operated according to the design limitations as the plant receives more amounts of influents then the design capacity. Also the plant needs continuous maintenance specially the aeration nozzles and pumps of the activated sludge tanks.

Table (1): Characteristics of the raw sewage (C), treated water after secondary treatment (F2), and filtered water after SSF

Test	Sample	Iraqi Standard	Min.	Max.	Avg.
BOD mg/L	C		160	300	230.95
	F2	40	55.36	103.8	79.91
	SSF		10	39	20.43
COD mg/L	C		255	861	404.82
	F2	100	98.073	331.1	155.74
	SSF		17	67	39.10
TSS mg/L	C		75	456	224.29
	F2	60	27.35	166.3	81.80
	SSF		10	47	27.05
pH	C		7.08	7.41	7.24
	F2	6.5 - 8.5	7.3	7.56	7.46
	SSF		7.12	7.3	7.15
Chloride mg/L	C		240	380	334.29
	F2	600	193.63	306.6	269.71
	SSF		97.2	153.9	135.39
BOD/COD Ratio	C		0.35	0.97	0.62
	F2		0.31	0.87	0.56
	SSF		0.23	0.65	0.42

Table (2): Characteristics of the average domestic sewage during study period.

Parameter	Influent (C)	After secondary treatment (F2)		After SSF		Overall removal %
		Effluent	Removal %	Effluent	Removal %	
BOD (mg/L)	230.95	79.91	65.40	20.43	73.84	91.15
COD (mg/L)	404.82	155.74	61.54	53.28	73.01	86.84
TSS (mg/L)	224.29	81.80	63.53	30.16	63.71	86.55
pH	7.24	7.46	----	7.20	----	
Chloride (mg/L)	334.29	269.71	19.32	135.39	49.80	59.50

Table (3): Sewage characterize ratios [12].

Type of sewage	BOD_5/COD	BOD_5/TOC
Untreated	0.3-0.8	1.2-2.0
After primary settling	0.4-0.6	0.8-1.2
Final effluent	0.1-0.3	0.1-0.5

4.3 Water quality improvements through SSF Performance

The slow sand filter was operated to improve the secondary effluent from Al-Rustamiya STP. Table 1 and 2 summarize the characteristics of the treated effluent (indicated as SSF). Table 2 shows the average concentrations of BOD_5, COD, TSS, and chloride in the effluent from the SSF which were 20.43, 39.1, 27.05 and 135.39 mg/L, respectively. At the end of the operation period, the SSF removal efficiency was 73.84% for BOD, 73.01% COD, 63.71% TSS, and 49.80% for chloride. The overall removal efficiency of Al-Rustamiya STP for BOD_5, COD, TSS, and chloride were 91.15%, 86.84%, 86.55%, and 59.50%, respectively. The study showed that SSF is very efficient to improve water quality of the secondary effluent from Al-Rustamiya STP to levels meeting the Iraqi regulations for disposal. Figs. 3, 4, 5, and 6 show the variation of BOD_5, COD, TSS, pH, and chloride in the raw sewage (C), effluent of the secondary treatment (F2) and effluent from the slow sand filer (SSF) during the study period.

5. CONCLUSIONS

Slow sand filters are simple and low-cost techniques which can be used as a tertiary treatment for the secondary effluent from Al-Rustamiya STP to improve the effluent quality for safe disposal to water bodies and reuse in irrigation. The results from this study have shown significant improvements in effluent quality parameters (BOD_5, COD, TSS, and chloride) due to slow sand filtration which were within the Iraqi or global regulations for disposal (APHA, 2012; Asano and Mills, 1990).

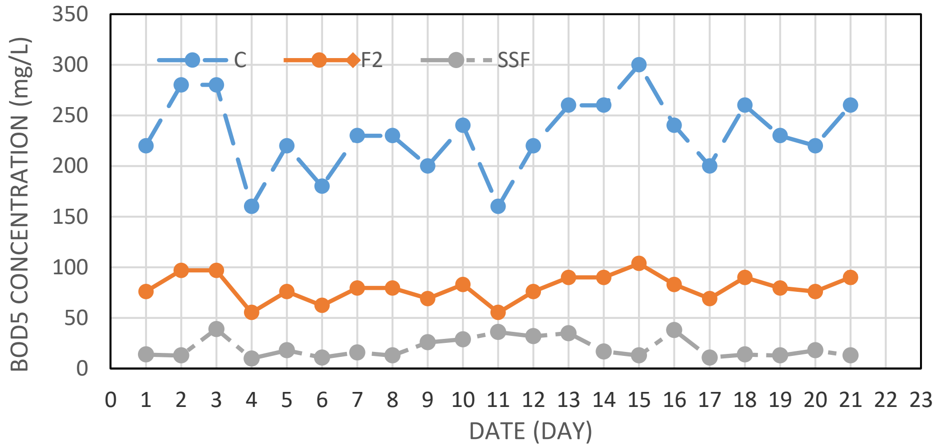


Fig. 3 Variation of BOD_5 in raw sewage, treated water after secondary clarifier, and filtered water after SSF.

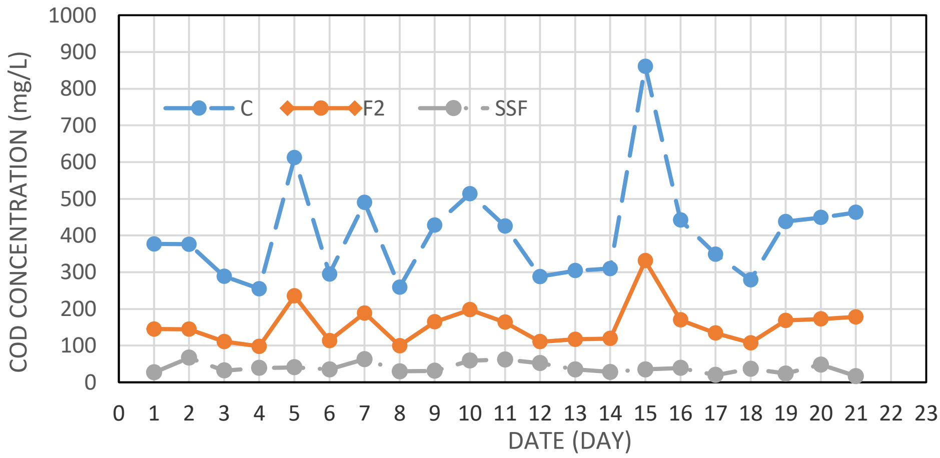


Fig. 4 Variation of COD in raw sewage, treated water after secondary clarifier, and filtered water after SSF.

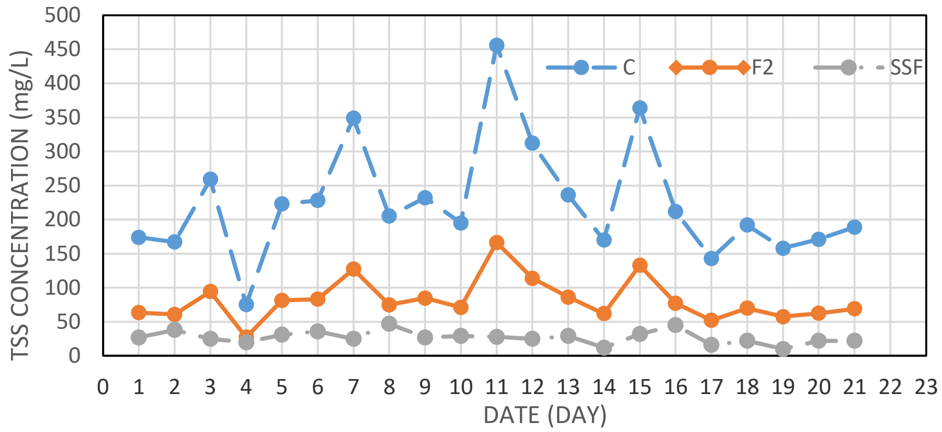


Fig. 5 Variation of TSS in raw sewage, treated water after secondary clarifier, and filtered water after SSF.

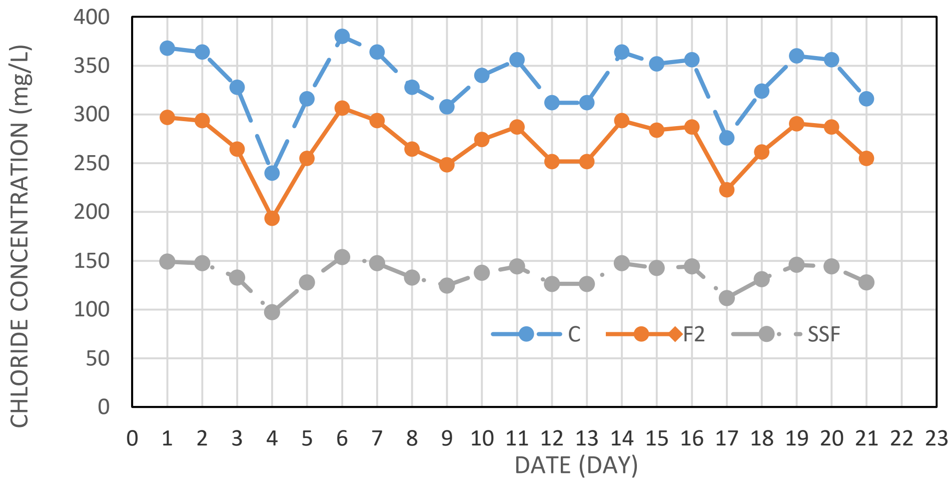


Fig. 6 Variation of chloride in raw sewage, treated water after secondary clarifier, and filtered water after SSF.

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الترشيح الرملي البطيء كمرحلة معالجة ثالثية للمطروحات السائلة الثانوية المطروحة من محطة معالجة مياه الصرف الصحي

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الخلاصة

تم تشييد مرشح رمل بطيء حقلي في محطة معالجة مياه الصرف الصحي في الرستمية ببغداد للتحقيق في كفاءة الإزالة من حيث تراكيز متطلب الاوكسجين الحيوي (BOD_5) ومتطلب الاوكسجين الكيميائي (COD) والمواد العالقة الكلية (TSS) والكلوريدات (Cl_2) من أجل تحقيق أفضل نوعية من المطروحات السائلة الثانوية للمحطة. وقد تم تصميم المرشح الرملي البطى بمعدل ترشيح (0.2) م/ساعة مع مساحة ترشيح (1) م^2 وعمق مرشح الكلي (2.3) م .مادة الرمل للمرشح ذو حجم (0.35) ملم وعمق (1) م مستند على طبقة من الحصى بسمك (0.2) م وحجم (5) ملم .استخدمت المطروحات السائلة الثانوية من محطة الرستمية كمياه داخلة الى المرشح الرملي البطى. وأظهرت النتائج أن نسبة إزالة متطلب الاوكسجين الكيميائي ومتطلب الاوكسجين الحيوي والمواد العالقة الكلية والكلوريد كانت 73.84٪، 73.01٪، 63.71٪ و 49.80٪، على التوالي بعد 28 يوما من عملية الترشيح الرملي البطى. وقد تحسنت كفاءة الإزالة الكلية لمحطة معالجة الرستمية من خلال هذه المعالجة الثالثية لتصل للمؤشرات اعلاه إلى (91.15٪، 86.84٪، 86.85٪ و 59.50٪) الذي يشير إلى أن المطروحات السائلة النهائية أصبحت مقبولة للأنظمة العراقية للتخلص منها.

الكلمات المفتاحية: الري الامن، عمق طبقة الرمل، المطروحات الثانوية، الترشيح الرملي البطى، المرحلة الثالثية، تثبيت مياه الصرف.