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ASSESSMENT OF MUNICIPAL WASTEWATER TREATMENT USING SEQUENCING BATCH REACTOR UNDER REAL OPERATION CONDITIONS

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Abstract

The Sequencing Batch Reactor system (SBR) is a major component of the municipal wastewater biological treatment system and water reclamation that provides high-quality water that could be reused in restricted plants that which require large quantities of water despite the lack of water. The research aims to investigate the performance of a pilot plant SBR unit under real operation conditions that was installed and operated in Al-Rustamiya Wastewater Treatment Plant (WWTP), Baghdad, Iraq. Results showed that the BOD_5/COD ratio of the raw wastewater was within the average value at 0.66 emphasizing the organic nature of the influent flow and hence the amenability to biological treatment. The results also ensured that the treatment process improvement occurred by increasing the detention time for settling of up to 4.5 hr under real operating conditions. The removal of BOD_5 and COD resulting from the treatment process of the SBR system reached 86% and 84% respectively, and the final effluent characteristics of SBR for 4 hr after settling time 3 and 4 hrs were within reuse within permissible limits for Iraqi quality standards for irrigation reuse (IQS-2012).

Keywords: Municipal wastewater treatment, Pilot-scale, Sedimentation, Sequencing batch reactor, Unrestricted water reuse.

1. Introduction

Water scarcity is a problem facing many countries of the world, although strict regulations emphasize the need to recycle effluent generated from different wastewater treatment plants for non-human contact applications such as toilet flushing and irrigation which can be economically feasible compared with effluent discharge and water supply [1]. The public health and environmental protection depend on the degree of reliability and type of the treatment process for recycling wastewater and reusing it as additional water resources with large amounts of wastewater that comes from urban sewage networks and the wastewater constituents depend on the urban area characteristics [2]. The reuse of treated wastewater is important for agriculture development; many farmers in Iraq have been utilizing wastewater without treatment, the most serious problems are related to pathogens, heavy metal contamination, and salinity accumulation. Some studies conducted in Iraq have shown that treated wastewater can be used to irrigate forage crops and some vegetables, but with little success in removing pathogens that reduce the opportunity to use treated effluents for unrestricted irrigation of high-value crops such as medicinal plants and vegetables [3].

The wastewater treatment plants (WWTP) aims to remove suspended and floating materials, biodegradable organic compounds, nutrients, and pathogens from wastewater that affect the selection of the treatment process technology. The coagulation and sedimentation processes improve the removal of the colloidal suspended solids from wastewater [4]. Many researchers have studied the physical and biological processes used in wastewater treatment to remove organic matter, soluble particles, and pathogens [5-7]. Recent studies have shown that decentralized wastewater treatment facilities for all rural residents are the best solution [8]. The main criteria affecting the technology used in low-cost wastewater treatment systems are land availability, skilled labour, implementation costs, operating and maintenance cost, energy supply, and the performance efficiency [9]. If there is a need to reuse treated effluent for irrigation, wastewater treatment should consider the removal of pathogens to the maximum possible extent while most of the nutrients and some biodegradable organic matter should be maintained [10]. The low-cost wastewater treatment systems may include many types as a septic tank, rotating biological contactor, stabilization ponds, and constructed wetlands [11].

The sequencing batch reactor (SBR) was first used in the early 1970s and gained popularity, mainly because of aerobic-anaerobic phases that occur in one unit with low aeration and low sludge production [12]. SBR is characterized as a better option for non-growth of algae, reducing Biochemical Oxygen Demand (BOD_5) and Total Suspended Solids (TSS) in one tank [13, 14]. It considers a plug or continuous flow batch reactor operating under different conditions during fill, react, settle, decant, and idle periods that formed a cycle [15, 16]. The use of these periods allows a single reactor to act as a reactor and a clarifier within a single working cycle. The SBR can accomplish most of the continuous flow plant that have several reactors and each operating under different conditions with the principle of filling and withdrawing in which unit processes occur sequentially on a cyclic basis. The SBR process differs from the activated sludge process which eliminates the need for primary and secondary clarifiers, and provides economic benefit [11, 17].

Some previous studies on the sequencing batch system for wastewater treatment from different sewage sources, Irvine et al. [15] found that batch systems eliminate algal growth common to lagoon systems, provide excellent removal of BOD and SS, and provide good nitrification and denitrification, Kumar and Chaudhari [18] studied the performance of sequential batch reactor (SBR) for simultaneous nitrogen and phosphorus removal from synthetic wastewater and they found that the phosphorus removal in the reactor was more than 80% and 90% nitrification was achieved.

Sundaramurthy et al. [12] modified a sequencing batch reactor (SBR) by adding membranes and diffusers in the design criteria to increase the efficiency treatment of industry wastewater. This technology enhanced the mineralization of the industry wastewaters containing toxic compounds have good efficiency. The results showed the BOD removal potency up to 98% and stable suspended solid effluent was obtained by the modified SBRs, while the phosphorus removal was low attributable to the limitation of organic process and Khudair and Jasim [19] conducted a study to evaluate the performance of Al-Rustamiya wastewater treatment plant using a reliability assessment for the a conventional activated sludge and sequencing batch reactors (SBR) as secondary treatment units and the results indicated due to inadequate sewage treatment that the effluents characteristics of both systems were not within the Iraqi standards due to operational problems in the plant.

This study aims to study the properties of municipal wastewater and the performance of a sedimentation tank and a sequencing batch reactor (SBR) for treating real municipal wastewater installed in Al-Rustamiya WWTP south of Baghdad city. Also, determine the best and shortest time to remove pollutions from municipal wastewater (TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4) compering the treated effluent with the Iraqi quality standards (IQS-2012) for the permissible levels of water reuse for irrigation purposes [20].

2. Material and Methods

2.1. Study area description

A field pilot plant was designed and installed in Al-Rustamiya WWTP located on the Diyala riverbank south of Baghdad city. The influent source to the pilot plant is of the real wastewater of Al-Rustamiya WWTP collected after the screens in a manhole. The wasted sludge from the sedimentation tank is collected in a holding tank as shown in Fig. 1. The primary sedimentation tank and SBR system were constructed and using a piping system to maintain the SBR system and to prevent the failure of important international technology and money loss. The pilot plant was designed, manufactured and operated in the Al-Rustamiya field which consists of an equalization tank, SBR and two integrated treatment schemes.

2.2. Data collection and analysis

Influent and effluent wastewater from SBR system was collected and analysed by Al-Rustamiya WWTP office/Baghdad Mayoralty from January to December 2019 according to the standard methods for water and wastewater examination (APHA) [21]. Table 1 shows the average annual concentrations of influent, effluent, and removal percentages of the selected parameters and the BOD_5/COD ratio for Al-Rustamiya conventional WWTP during the study period.

Table 1. Wastewater analysis of Al-Rustamiya WWTP in 2019.

Parameter	In	Out	%
BOD, mg/L	274.5	26.6	90.3
COD, mg/L	411	36.16	91.2
TSS, mg/L	207.5	22.8	89
pH	7.4	7.8	
Chloride, mg/L	312.8	256	18.2
BOD_5/COD	0.47	0.49	

3. System Configuration

3.1. Pilot plant and operational conditions

Figure 1 shows the field pilot plant diagram, the SBR unit was operated using municipal wastewater at Al-Rustamiya WWTP, Baghdad, Iraq. The wastewater was treated through three chambers baffled, first in a degreasing and settling tank, 0.5 m^3, as a primary treatment, and second the primary effluent was then directed to SBR for treatment.

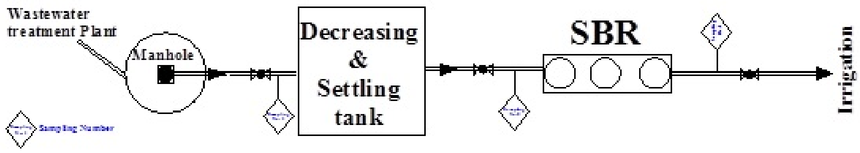

Fig. 1. Schematic diagram of the treatment system.

3.2. Degreasing and settling tank

A tank with working volumes of 0.5 m^3, 1.0 m length, 0.9 m width and 1.0 m height were employed for wastewater degreasing, made from Polyvinyl Chloride (PVC). This rectangular tank installed about four meters above the ground surface, and it consists of three chambers separated by baffles for suspended solids settling with dimensions of 0.4 m, 0.3 m, and 0.3 m in length, 0.9 m in width and 1.0 m in depth as shown in Fig. 2. The influent flow rate to the degreasing tank is 160 litre/hour with surface overflow rate (SOR) about 1.43 m/h, and detention time is 120 minutes.

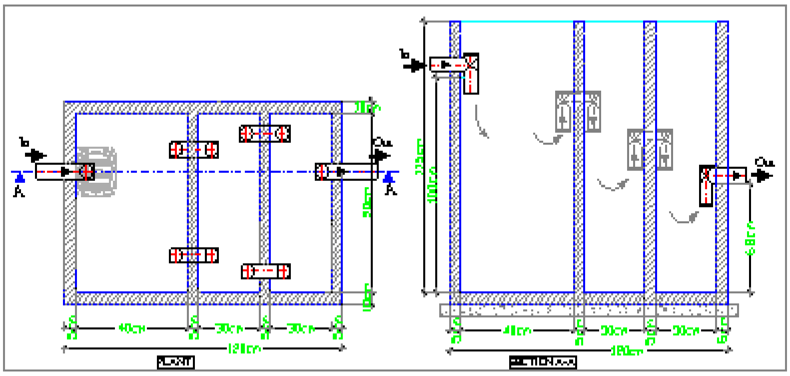

Fig. 2. Details of degreasing and settling tank.

3.3. SBR plant unit

The SBR system is applicable to the proposed activated sludge and the most promising modification to remove nutrients and organic carbon [17, 22], due to the operating process is flexible, simple, and increasingly popular for the domestic and industrial wastewater biological treatment [23]. A fully automatic biological-mechanical process for SBR is comprised of five phases (fill, react, settle, decant, and idle periods), as shown in Fig. 3.

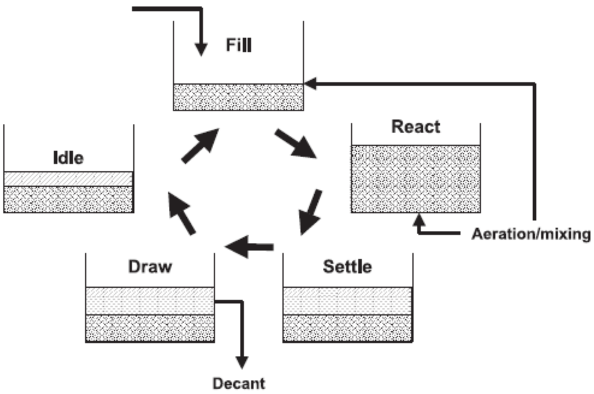

Fig. 3. The SBR phases throughout the study.

SBR systems are uniquely suited to wastewater treatment applications that have intermittent and/or low flow conditions and useful for a limited area of land. Additionally, wastewater is collected from the manhole, separately and treated for reuse in an SBR with a capacity of 300 L/cycle. It comprises a step biological treatment process with bacteria growing on a fixed bed of foam cubes of the treated wastewater before storage and a buffer tank with a volume of 100 L. A fully automatic, biological-mechanical process for SBR was contained in four phases, as shown in Fig. 3. The SBR was inoculated with 2.0 litres of biomass taken from the existing activated sludge unit in Al-Rustamiya WWTP for microbial growth with daily renewal of wastewater. The specifications of the SBR are given in Table 2.

Table 2. Specifications of the SBR unit.

Item	Specification
Maximum flow rate L/min	5 ~ 35
Number of tanks	3
pH range	1.5-10
Temperature, °C	4 ~ 35
Capacity of all three tanks, L	300
Recycling capacity, max. L	200

The reactor was continuously aerated for 12 hours to maintain the dissolved oxygen concentration (DO) at 4.0 mg/L, to ensure organic material oxidation in reactor, and the settling time (3.0 hours) to achieve well stable sludge and pure supernatant of the reactors.

3.4. Sampling and analytical methods

The sampling analysis was conducted continuously during the study period to investigate the wastewater treatment efficiency of the SBR system. The samples were collected from the SBR treatment unit and analysed according to the standard methods of water and wastewater examination [21], namely pH, Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Total Kjeldahl Nitrogen (TKN) and Ammonia (NH_4).

4. Results and Discussion

4.1. Raw wastewater characteristics assessment

The raw wastewater characteristics during the study period showed both diurnal and seasonal variation, especially in seasons and holidays. Table 3 represents the weekly chemical and physical analysis of the raw wastewater during all the studied processes were carried out according to the Iraqi Quality Standard (IQS). The results showed that the concentrations of TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4 were within high levels. The BOD_5/COD ratio was observed within the range from 0.67 to 0.69 at an average of 0.66, indicating that the organic nature was amenable for biological treatment that is consistent with the research results [7, 11, 17]. The wastewater temperature ranged between 16.71 and 38.92°C.

Table 3. Raw wastewater Characteristics during study period.

Parameter	Minimum value	Maximum value	Average value
pH	7.09	8.66	7.87
T_W, ºC	16.71	38.92	27.81
TSS, mg/L	150	265	207.5
COD, mg/L	289	563	411
BOD_5, mg/L	185	393	274.5
TP, mg/L	2.5	3.9	3.2
Ratio BOD_5/COD	0.67	0.69	0.66
NH_4, mg/L	18	26.5	22.25
TKN, mg/L	33.7	58.5	46.1

4.2. Pilot Plant Experiments

4.2.1. Influence of Settling Times on Sedimentation Tank Performance

The removal efficiency of the sedimentation tank (ST) based on TSS, BOD_5, and COD reached 65%, 21%, and 25% respectively, when the retention time was usually (3.0-4.5) hours. The removal efficiency showed that the optimum settling time was 4.5 hours, which is enough to removal the pollution parameters. Nevertheless, this time was considered a very long time. Therefore, the detention time was selected (3.0 and 4.0) hours for settling time in this study. The degreasing and settling as pre-treatment without using of SBR to remove oil and grease, larger particles and sludge materials were achieved slightly removal of COD, BOD_5, and good TSS ranged from (392~ 386, 204~201, and 101~80) mg/L, respectively with the removal efficiency of TP, NO_3, TKN, and NH_4, was 29%, 21%, 14%, and 31% respectively as shown in Table 4 [11, 16].

Table 4. Influence of settling times on removal efficiency.

Parameter	Raw Waste Water	Settling Time					
		3.0 hr		4.0 hr		4.5 hr	
		Average value	% R	Average value	% R	Average value	% R
T_W, °C	24.93	24.90	-	25.00	-	25.00	-
pH	6.93	7.11	-	7.23	-	7.25	-
TSS, mg/L	231.10	100.88	56.35	80.33	65.24	58.55	74.66
COD, mg/L	514.50	392.50	23.71	386.51	24.88	385.67	25.04
BOD_5, mg/L	256.90	203.77	20.68	201.75	21.47	197.25	23.22
TP, mg/L	4.40	3.33	24.32	3.11	29.32	3.11	29.32
NO_3, mg/L	5.25	4.29	18.28	4.21	21.52	3.98	24.19
TKN, mg/L	50.22	43.22	13.94	43.1	14.18	43.10	14.17
NH_4, mg/L	23.00	12.50	45.65	15.89	30.91	17.88	22.26

4.2.2. SBR performance

Table 5 represents the results obtained by treating the wastewater by SBR for 12 hours after 3.0 hours settling time. The organic loading rate was 148.5 kg BOD/m^2/day, and 235.7 kg COD/m^2/day where the overall removal was 76%, 67%, 57%, 91%, 43%, 73%, and 52 % for TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4, respectively. The final wastewater effluent quality did not conform with the permissible limits of the Iraq quality standard or with the quality standard for water sources [16, 20].

Table 5. Influence of settling time (3hr) and SBR cycle time (12hr) on removal efficiency.

Parameter	Average Raw wastewater concentratio	Settling Tank		SBR		Overall removal %	ISQ
		3 hr		12 hr			
		Average	%R	Average	%R		
TSS, mg/L	231.10	100.88	56.34	75.77	24.89	67.21	60.00
COD, mg/L	514.50	392.50	23.71	167.22	57.40	67.49	100.00
BOD_5, mg/L	256.90	203.77	20.68	109.35	46.34	57.43	40.00
TP, mg/L	4.40	3.33	24.31	0.41	87.69	90.68	2.00
NO_3, mg/L	5.25	4.29	18.28	2.98	30.54	43.23	50.00
TKN, mg/L	50.22	43.22	13.94	13.75	68.19	72.62	-
NH_4, mg/L	23.00	12.50	45.65	11.00	12.00	52.17	5.00

The reduction of the detention time to 8 hours in the for SBR unit at settling time about 3.0 hours effected the treatment process. The results showed that the removal reached 79%, 77%, 69%, 90%, 45%, 70%, and 56% for TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4, respectively, as shown in Table 6. The organic loading rate was 223.4 kg BOD/m^2/day, and 353.6 kg COD/m^2/day. The characteristics of this effluent were 67.45, 119.7, 78.7, 0.45, 2.88, 12.7, and 10 mg/L, respectively. It is worth noting that the of this final wastewater effluent quality was not within the allowable limit for Iraqi irrigation reuse standards (IQS-2012) as shown in Table 6 [15, 20].

Table 6. Influence of settling time (3 hr) and SBR cycle time (8hr) on removal efficiency.

Parameter	Raw wastewater concentration	Settling Tank 3 hr		SBR 8 hr		Overall removal %	ISQ
		Average	%R	Average	%R		
TSS, mg/L	231.10	100.88	56.34	67.45	33.14	70.81	60.00
COD, mg/L	514.50	392.5	23.71	119.74	69.49	76.72	100.00
BOD_5, mg/L	256.90	203.77	20.68	78.77	61.34	69.33	40.00
TP, mg/L	4.40	3.33	24.31	0.45	86.49	89.77	2.00
NO_3, mg/L	5.25	4.29	18.28	2.88	32.87	45.14	50.00
TKN, mg/L	50.22	43.22	13.93	12.75	70.50	74.61	-
NH_4, mg/L	23.00	12.50	45.65	10.00	20.00	56.52	5.00

The results showed that the reduction of the detention time to 6 hours in the SBR unit with settling time 3.0 hours effected the removal efficiency as it reached 85%, 83%, 87%, 89%, 45%, 75%, and 56% for TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4, respectively. The organic loading rate was 298 kg BOD/m^2/day, and 471.5 kg COD/m^2/day as shown in Table 7. Meanwhile, the characteristics of the TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4 were 34, 89, 32, 0.48, 3, 12.6, and 10.11 mg/L, respectively. The final wastewater effluent characteristics at this stage were within the allowable Iraqi Quality Standards for irrigation reuse [16, 20].

Table 7. Influence of settling time (3hr) and SBR cycle time (6hr) on removal efficiency.

Parameter	Average Raw wastewater concentration	Settling Tank 3 hr		SBR 6 hr		Overall removal %	ISQ
		Average	%R	Average	%R		
TSS, mg/L	231.10	100.88	56.34	53.97	46.50	76.64	60.00
COD, mg/L	514.50	392.50	23.71	88.88	77.36	82.72	100.00
BOD_5, mg/L	256.90	203.77	20.68	32.56	84.02	87.32	40.00
TP, mg/L	4.40	3.33	24.31	0.48	85.59	89.09	2.00
NO_3, mg/L	5.25	4.29	18.28	2.90	32.40	44.76	-
TKN, mg/L	50.22	43.22	13.93	12.65	70.73	74.81	-
NH_4, mg/L	23.00	12.50	45.65	10.11	19.12	56.04	5.00

The results indicated that 4 hours' detention time in the SBR unit with increasing the settling time in the pre-treatment process to 4.0 hours increased the organic loading rate to 446 kg BOD/m^2/day, and 707 kg COD/m^2/day. Where the removal efficiency reached 78%, 84%, 86%, 90%, 37%, 74%, and 44% for TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4, respectively as shown in Table 8. The characteristics of the TSS, COD, BOD_5, TP, NO_3, TKN, and NH_4 were 51, 84, 36, 0.44, 3, 13.15, and 13 mg/L, respectively. These treatment operating conditions produced an effluent within the allowable Iraqi Standards for irrigation reuse [17, 20].

Table 8. Influence of settling time (4hr) and SBR cycle time (4hr) on removal efficiency.

Parameters	Raw wastewater concentration (Average)	Settling Tank 4 hr		SBR 4 hr		Overall removal %	ISQ
		Average	%R	Average	%R		
TSS, mg/L	231.10	80.33	65.24	50.73	36.85	78.04	60.00
COD, mg/L	514.50	386.51	24.87	84.22	78.21	83.63	100.00
BOD_5, mg/L	256.90	201.75	21.46	36.35	81.98	85.85	40.00
TP, mg/L	4.40	3.11	29.31	0.44	85.85	90.00	2.00
NO_3, mg/L	5.25	4.12	21.52	3.30	19.9	37.14	50.00
TKN, mg/L	50.22	43.10	14.17	13.15	69.49	73.81	-
NH_4, mg/L	23.00	15.89	30.91	12.88	18.94	44.00	5.00

5. Conclusions

From the results obtained from the pilot-scale sequencing batch reactor (SBR) installed in Al-Rustamiya WWTP under real operation conditions, the following can be concluded:

- The average ratio of BOD_5/COD was within the range of 0.66, indicating the raw wastewater characteristics of organic nature, amenable to biological treatment.
- The removal efficiency of TSS, BOD_5, and COD with the optimum settling time 4.5 hr of the sedimentation tank emphasizes that this tank operating under real operation conditions is within the criteria design.
- The final effluent characteristics of implementing the SBR unit for 8 and 12 hr after 3 hr settling time could not successively fulfil the permissible limits of the Iraqi Standards for the quality of water sources.
- The final effluent characteristics of SBR for 4 hr after settling time about 4 hr are within the permissible limits of Iraq quality Standard (IQS-2012) according to the quality standard for irrigation reuse.
- The final wastewater effluent from SBR was of excellent quality which can be used for different purposes according to the criteria required for unrestricted reuse. SBR demonstrates effective and reliable technology for removing contaminants from wastewater and noted that the batch experiments have been conducted to obtain the best operating conditions.

Abbreviations

BOD_5	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
IQS	Iraqi Quality Standards
MBR	Membrane Bioreactor
NH_4	Ammonia
PVC	Polyvinyl Chloride
SBR	Sequencing Batch Reactor
SOR	Surface Overflow Rate

ST	Sedimentation Tank
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphates
TSS	Total Suspended Solid
WWTP	Wastewater Treatment Plant

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