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Automotive services wastewater treatment using sequencing batch reactor: Startup and performance

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ABSTRACT

The proper start-up period, as well as process performance verification, are essential for the successful operation of biological treatment systems. The objective of the study was to investigate experimentally the start-up process and operational performance of a sequencing batch reactor (SBR) system used in treating automotive services oily wastewater generated from Hamdan Industrial Zone (HIZ) in Basrah governorate, south of Iraq. The study involved the analysis of different physiochemical parameters present in the wastewater. Its results revealed that the start-up (or microbial acclimatization) period of the employed system is about 36 days. During this period, the concentration of MLSS and MLVSS gradually increased over time to 5012 and 3285 mg/L, respectively. At the time of maximum MLSS occurrence, the achieved SVI was 72 ml/g. The SBR performance results, gathered by influent and effluent analyses, showed that the COD, BOD, and oil and grease removal efficiency values varied in the ranges (71.1–75.1), (81.9–85.0), and (66.7–68.4) %, respectively. The VSS, TSS, NBSCOD, and NBPCOD removal efficiencies vary in the ranges (57.5–81.2) (59.8–82.0), (63.8–66.5) and (53.8–75.5) %, respectively. When the SBR effluent concentrations of BOD5, COD, TSS, and oil and grease were compared with their permissible limits of Iraqi regulations, it was noticed that all these parameters did not comply with their permissible limits. On the basis of the study findings, the SBR system used to treat oily wastewater generated by automotive services needs to be improved by adding innovative treatment technologies to comply the quality of treated wastewater with the standard specification regulations.

Keywords: automotive services, wastewater, sequence batch reactor, startup, performance, Hamdan Industrial Zone

INTRODUCTION

The wastewater discharged from automotive service stations forms an environmental challenge due to the presence of a wide spectrum of pollutants. This wastewater is generated by different daily activities related to vehicle maintenance (washing, lubrication, and painting), repair, besides the sanitary wastewater. The majority of these activities generate significant amounts of wastewater that must be treated before its final disposal (Neha and Chandrakant, 2017). Therefore, a proper treatment scheme must be selected to produce an effluent meets the environmental regulations and sustainability control the disposal of this wastewater to the surrounding environment.

Different treatment methods were applied for treating automotive services wastewater. Zaneti et al. (2013) monitored a full scale plant for treating car wash wastewater adopting flocculation–column flotation, sand filtration and chlorination unit. They indicated that the plant effluent can be reused for car washing. Sarioglu and Gökcek (2016) investigated the treatment of automotive wastewater using anaerobic batch reactor. The wastewater has biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil and grease maximum values of 70000, 90000, and 700 mg/l. respectively. The anaerobic reactor satisfied a maximum COD removal percentage of 47%. Mujumdar et al. (2020) performed a lab study adopting conventional water treatment train included five processes in series (screening, coagulation, flocculation, sedimentation and filtration) for treating car wash wastewater. They indicated that the maximum values of COD, BOD, as well as oil and grease in car wash raw wastewater were 1200, 68, and 310, respectively, whereas the system removal efficiencies of COD, BOD, as well as oil and grease were (55–60), (75–80), and (70–75)%, respectively. Wang et al. (2021) applied a treatment system composed of activated sludge and aerobic granular sludge processes for treating automobile coating wastewater has maximum values of COD, TN, TP, and phenol of 1000, 40, 25, and 45 mg/l, respectively. They revealed that the system startup period was 15 days and after 50 days of system operation, the removal percentages of COD, total nitrogen (TN), total phosphorus (TP), and phenol were 85, 82, 62, and 90%, respectively. Irsan and Soeryamassoeka (2022) investigated experimentally the performance of a biofilter in treating car wash wastewater. They examined numerous media types, including: palm fiber, gravel, activated charcoal, bio ball, filter cotton, coarse fiber, silica sand, and gauze. However, the authors did not present any data regarding the biofilter performance. Latha et al. (2023) compared the performance of two systems in treating automotive wastewater. The first system applied coagulation process using alum, while the second system applied a filter bed using sawdust and sugarcane bagasse. They showed that the performance of both systems varied mainly according to the wastewater composition. Ahmed et al. (2024) applied a lab scale conventional water treatment system for treating car wash wastewater. They showed that the treatment system can remove turbidity, COD, and oil at percentages of 96.5, 88.6, and 93.8%, respectively. Torrens et al. (2025) examined the performance of three natural wastewater treatment systems (vertical flow wetland, horizontal flow wetland and infiltration–percolation filter) in treating the wastewater generated from car wash stations in Girona, Spain. The study results showed that the vertical flow wetland and infiltration –percolation filter systems were efficient in treating the car wash wastewater and can lower the stream COD below 20 mg/l where the influent COD, BOD, as well as hydrocarbons and oil were 438, 70, and 0.6 mg/l, respectively. In turn, the horizontal flow wetland was not efficient and suffered from a clogging problem, which reduced its hydraulic capacity.

From reviewing the above previous studies, it was noticed that most of these studies had considered the treatment of car wash wastewater. In fact, there are many industrial areas where most of car maintenance and repair activities are done at the same site like the case of Hamdan Industrial Zone (HIZ) in Basrah governorate, south of Iraq, which is the main industrial zone for automotive (cars, trucks, motorcycles, etc.) services (Al-Asadi et al., 2024). HIZ was, recently, provided with a sewer system completed with a wastewater treatment plant. The plant employed a conventional treatment system adopting a sequencing batch reactor (SBR) as a biological treatment system for removing the organic pollutants present in the wastewater. However, in accordance to the unpublished data recorded by the lab of Basrah Sewerage Directorate, in less than three years, the plant malfunctioned in removing the organic pollutants.

The SBR has been widely investigated as one of the most flexible wastewater treatment systems with high efficiency and small footprint (Mace and Mata-Alvarez, 2002). It is a cyclic activated sludge process performed in single reactor by repeating the sequential stages: filling, reaction with or without aeration, settling, decanting and idle phases (Metcalf and Eddy, 2014). SBR is applicable to both domestic and industrial wastewater, the properties of which vary depending on the fluctuation of the load and the change in pollutant composition (Chan et al., 2009).

From the literature review presented above, none of the previous studies had considered the treatment of automotive wastewater using SBR. Thus there is no knowledge in this concern. Besides, to detect the reasons behind the SBR failure in treating the automotive wastewater generated from HIZ, it was decided to construct an experimental rig for SBR and operate using automotive wastewater drawn from the influent of the HIZ treatment plant.

The aim of this study was to investigate the start-up process and operational performance of the SBR system used in treating automotive services wastewater. The proper start-up period as well as process performance evaluation are essential for the successful operation of any biological treatment systems. During the start-up period, sustainable and stable microbial communities are created that have the ability to degrade and eliminate the pollutants in wastewater (Khalili et al., 2013). The startup phase in biological treatment systems is successfully completed either when the microorganisms in a treatment plant develop and grow within the desired levels specified in its design, or when they acclimate to the final environmental conditions. In the activated sludge reactor, a steady state is usually reached at approximately

80 to 100 days using fresh sludge obtained from a wastewater treatment plant. This period is significantly reduced, to about 25 to 30 days using an acclimatized sludge (Gali et al., 2006 and Jubany et al., 2008). In this study, the SBR performance was evaluated by determining the removal efficiency percentages of COD, BOD, oil and grease, suspended solids, non-biodegradable soluble and particulate COD (NBSCOD and NBDPCOD).

MATERIALS AND METHODS

Description of experimental rig

In order to accomplish this study, an experimental rig for SBR was constructed glass (for manufacturing the tank) and steel (for manufacturing the supporting structure) workshops. The tank with the steel support structure was transported to the Department of Civil Engineering and installed in Fluid Mechanics Laboratory. Figure 1 shows a schematic diagram for the constructed SBR experimental rig. The rig consists of the following main parts, in addition to piping works and control valves:

1. A glass rectangular tank of 1 cm wall thickness had clear dimensions of 148 cm length, 33 cm width, and 70 cm total depth. The total volume of the tank was 341.9 liters and its working volume was 293 liters. The tank was supported by a steel structure with wheels to facilitate its movement.
2. Air supply system which was composed of air compressor of 125 L/min capacity, 40 kPa pressure, and 135 W power, in addition to a standby air compressor system with 250 L/min capacity, 800 kPa pressure, and 2.2 kW power. The air was supplied to the SBR tank using three circular diffusers, each having a diameter of 26 cm, the air diffusers were made of plastic and rubber membrane with fine holes that dispersed the air bubbles into the SBR during the reaction phase.
3. Three pumps for filling the SBR, decanting the effluent, and withdrawing the excess sludge. Each pump had a max capacity of 110 L/min, max head of 30 m, and a power of 750 W.
4. Influent feed tank which was a plastic tank of 500-liter capacity.
5. Three flow meters for controlling the influent flow rate (40 l/min max reading), decant flow rate (21 L/min max reading) and air supply rate (50 L/min max reading).
6. Mixer, GCO type, with multi-speed rotation (0–500 rpm) and 1400 W power

Start-up process of SBR

After the completing the erection of the SBR experimental rig, it was operated using tap water. That was to check the leak tightness of the tank and piping works and the performance of air diffusers, blower, pumps, and flow meters. The SBR was filled with water and air was pumped. After

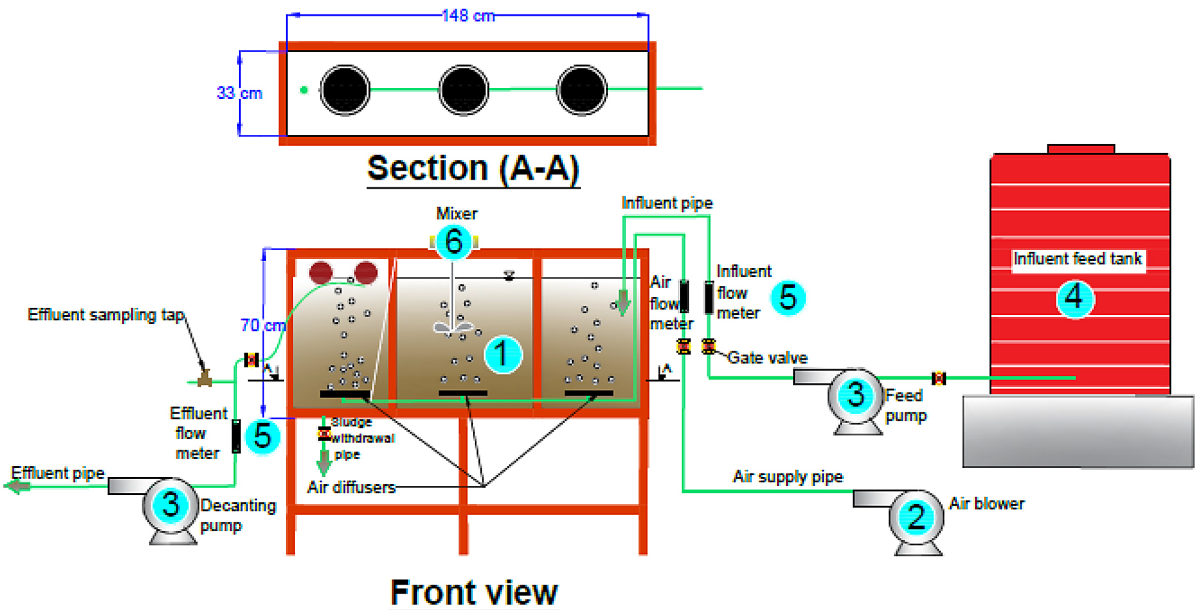


Figure 1. Schematic diagram for the constructed SBR experimental rig

ensuring the system tightness against leak and the proper working of all the equipment, the start-up period of the SBR was commenced.

The design parameters required for SBR system include; mixed liquors suspended solid (MLSS), food to microorganisms' ratio (F/M), sludge retention time (SRT), hydraulic retention time (HRT) and total cycle time. The values of these parameters are presented in Table 1.

During the start-up period, it was noted that at the first week of the SBR operation, the values of MLSS and sludge volume index (SVI) were below their design limits. Thus, it was required to seed active biomass (sludge). The activated sludge was taken from the aeration tank of an activated sludge system in the Al-Thagher wastewater treatment plant, which is located in Al-Thagher city, northern of Basrah governorate. Forty liters of activated sludge were added to the SBR and the remaining volume was completed with raw wastewater taken from the influent of the HIZ treatment plant fed and withdrawn daily in accordance to the total cycle time phases of 24 hours. In addition, nutrients were added to accelerate the microorganisms' growth rate and acclimatize them with the type of wastewater to be treated (OWW). The air was continuously supplied at a flow rate of 25 L/min and wastewater samples were taken to measure MLSS and SVI. The steady state of SBR operation was reached during the period from 21 to 26 days, where the highest MLSS value was obtained. The acclimatization period (start-up phase) took about 36 days, starting from 5/3/2024 to 10/4/2024, when MLSS and VSI were found to be within the recommended ranges in Table 1. Figure 2 shows the volumes of the developed activated sludge before seeding the active sludge and after completing the acclimatization period (start-up phase).

SBR operation

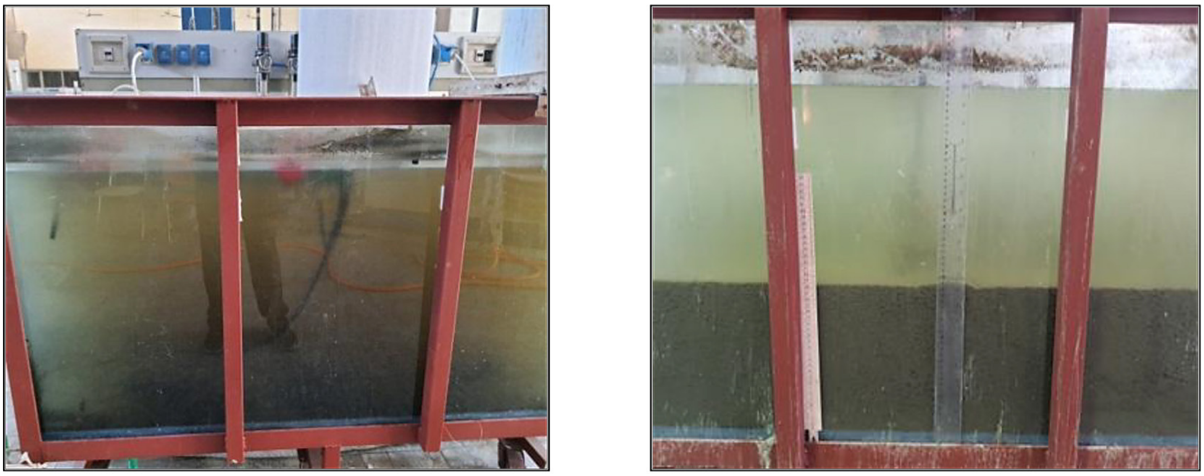
After reaching the steady state of SBR, it was operated for two weeks to examine its performance in treating the OWW generated from HIZ. The SBR operation was carried out applying a total time cycle of 24 hours divided into fill, react, settle, decant, and idle phases of 0.5, 21, 1.75, 0.5, 0.25 hour, respectively, by adopting the following steps:

1. The feed tank was filled with the raw OWW transported from HIWWTP.
2. Fill phase: The SBR tank was filled with the raw wastewater from the feed tank by the influent pump within a duration of 30 min at a flow rate of 10 l/min, then a sample of the incoming wastewater was taken for the analyzing the characteristics of the raw wastewater for each treatment cycle. The mixer operated during this stage to ensure the uniform distribution of the active sludge over the bulk volume of the wastewater in the tank.
3. React phase: The air compressor was turned on to supply the air at a rate of 25 l/min to the reactor for 21 hours, and the diffusers distributed the fine air bubbles over the bulk volume of the reactor. During this stage, the mixer operated to ensure good mixing and the dissolved oxygen was measured to be in the range (3.8–5.3) mg/L.
4. Settle phase: During this operation phase, which had a duration of 1.75 hour, the wastewater was kept under calm conditions, to allow the settlement of suspended solids, by turned off both the air supply and mixing equipment.
5. Decant phase: During this phase, the effluent pump was operated at a flow rate of 10 l/min for a duration of 30 min to withdraw the clear upper water.
6. Idle phase: During this phase, some of sludge may be withdrawn to maintain the required MLSS concentration in the reactor. It is the

Table 1. Design parameters of SBR (Velmurugan et al., 2010 and USEPA, 1999)

Parameters	Value or values range		
	Municipal	Industrial	Typical SBR
MLSS (mg/l)	2000–2500	2000–4000	2000–6500
F:M (g BOD/g MLVSS/d)	0.15–0.4	0.15–0.6	0.04–0.2
HRT (h)	6–14	Varied	9–30
SRT (d)	–	–	20–40
Total cycle time (h)*	4	4–24	4–12
Sludge wasting	As required to maintain MLSS within limits		

Note: *Cycle time value is adjusted according to effluent quality requirements and wastewater flow rate (Haandel and Lubbe, 2012).



(a) Before seeding (b) After seeding

Figure 2. Activated sludge development in the SBR; (a) Before seeding, (b) After seeding

final stage of the operating cycle, where the reactor is prepared for a new cycle.

These six phases of SBR operation were repeated continuously throughout the study period, and influent as well as effluent wastewater samples were taken for each operating cycle for the purpose of evaluating the reactor efficiency in removing the considered pollutants.

Wastewater sampling and analysis

Samples of wastewater were collected using plastic containers from the influent (raw wastewater) and the effluent during the decant phase. Each sample was analyzed in the Lab of Sanitary Engineering to determine the values of the important parameters that indicate the efficiency of the applied system in treating OWW.

In this study, the considered parameters include; COD, BOD_5, oil and grease, TSS, TVSS, total dissolved solid (TDS), dissolved oxygen (DO), pH and temperature. In addition to the values of NBSCOD, NBPCOD, and sludge volume index (SVI) were measured. SVI was mainly of concern during the start-up period of the SBR. The DO, pH, TDS, and temperature were on-site measured using a Hach HQ30D portable meter. The samples used for analyzing the BOD_5, COD, oil and grease, TSS, and non-biodegradable soluble chemical oxygen demand (NBSCOD) were preserved at a temperature of 4 °C and transported to the lab. BOD_5 and COD were measured using Lovibond OxiDirect and DR 5000 UV-Vis Laboratory Spectrophotometer, respectively. Oil and grease as well as TSS were measured in accordance to the standard methods 5520 B (partition-gravimetric method) and 2540 B, respectively (APHA, 2017).

The NBSCOD in wastewater was measured following the method of biodegradation-coagulation (Hu et al., 2002 and Choi et al., 2017). The method procedure includes subjecting the sample to six processes in sequence; aerobic biodegradation for 24 hours, sedimentation for one hour, rapid mixing, to accomplish coagulation by the addition of zinc sulfate and sodium hydroxide, for 1 minute, and slow mixing, to accomplish flocculation, for 5 minutes, sedimentation for 1 hour, and filtration using Whatman nylon filter discs of 0.45 µm pore size to remove the particulates. Then, COD was measured for the filtrate. The obtained COD value was recorded as NBSCOD. The non-biodegradable particulate COD (NBDPCOD) was determined by subtracting the values of BOD and NBDSCOD from the total COD value.

Removal percentage

The SBR performance in removing the different considered pollutants was measured in terms of removal percentage. The removal percentage of any pollutant, such as COD, was calculated as;

$$\% \text{ of } COD \text{ removal} = \frac{COD_{in} - COD_{eff}}{COD_{in}} \times 100 \quad (1)$$

where: COD_{in} and COD_{eff} are influent and effluent COD values, respectively.

RESULTS AND DISCUSSION

Wastewater characteristics in Hamdan Industrial Zone

Seventeen samples of the raw wastewater generated from automotive services in HIZ were analyzed for the considered parameters and the obtained results are presented in Table 2. This table shows the minimum, maximum, average, and standard deviation of each considered parameter. The presented results revealed that the raw wastewater generated from the automotive services in HIZ can be characterized to be oily, saline, organically polluted, slightly alkaline, and of high strength. It has biodegradability index values that vary in the range (0.38 to 0.49) and thus it is not easily biodegradable. The values of NBDSCOD and NBDPCOD in the raw wastewater vary over the ranges (336–448) and (266–571) mg/l, respectively. The study results showed that the major part of the non-biodegradable organics that may be removed by the settling is particulate.

Start-up period characteristics of SBR

During the start-up period, activated sludge was seeded to increase the MLSS concentration to the required level for SBR operation (2000–6500 mg/l) (USEPA, 2002). The development of the activated sludge volume was monitored every day by testing the settled sludge volume and plotting the results with a graph of the settled sludge volume (SSV) versus time in minutes. Figure 3 shows the settled sludge volume at different operating times during the start-up period of SBR. It shows that the SSV values decrease with the increase of operation time. That indicates the settleability of activated sludge is increasing with time which means it can be removed from the treated wastewater at a low detention time. Also, the temporal variation of SSV has got a similar trend after the 25th day of SBR operation start.

The biomass growth and its acclimatization in the SBR were detected by examining MLSS and MLVSS as well as SVI; the results are shown in Figures 4 and 5. The initial concentrations of MLSS, MLVSS and SVI, after seeding, were 2516 mg/l, 1324 mg/l and 262 ml/g, respectively. With the continuation of the acclimatization process and daily operation, the concentration of MLSS and MLVSS gradually increased over time until the biomass growth reached a steady state in the period of (21–26) days.

The highest values of MLSS and MLVSS were 5012 and 3285 mg/l, respectively, and these values were obtained on the 21th and 24th day from the start of operation, respectively. At the time of maximum MLSS occurrence, the achieved SVI was 72 ml/g. These operation conditions were lasted for three days. After that, the MLSS and MLVSS values began to gradually decrease until they reached 4511 and 2805 mg/l, respectively. SVI was calculated to be 55 ml/g on the 30th day of the startup stage. This indicates that the biomass represented by MLVSS gradually grew and developed until it reached a stable state in the period (21–26) days, and then it began to decrease, indicating that it reached the death phase of the growth stages, and converted into a solid material that can be settled. Generally, the obtained SVI values after the biomass acclimation were within the SVI values range for activated sludge systems that is (50–150) ml/g (Wongburi and Park, 2022).

Table 2. Characteristics of HIZ raw wastewater

Parameter	Unit	Min	Max	Average	Sta. Dev.
COD	mg/l	1220	1684	1540	149.4
BOD		565	728	652	57.7
Oil and grease		351	423	392	22.8
TS		34670	54685	45169	4980.3
NBDSCOD		336	448	392	27.4
NBDPCOD		266	571	418	93.53
DO		0.01	0.24	0.12	0.06
TDS		32600	42800	38612	2465.5
pH	-	7.01	8.30	7.63	0.4
Temp.	°C	23.5	35.1	27.4	2.8
BOD/COD	-	0.38	0.49	0.42	0.03

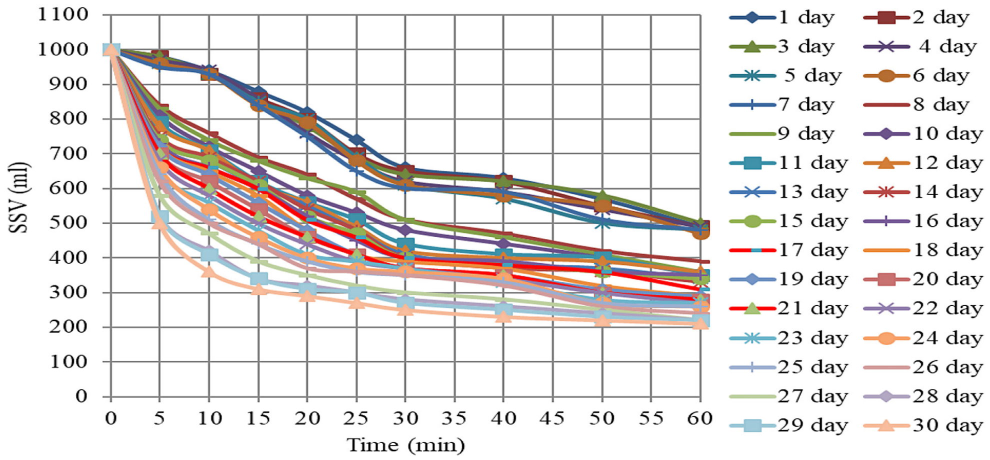


Figure 3. Settled sludge volume at different operating times during the startup period of SBR

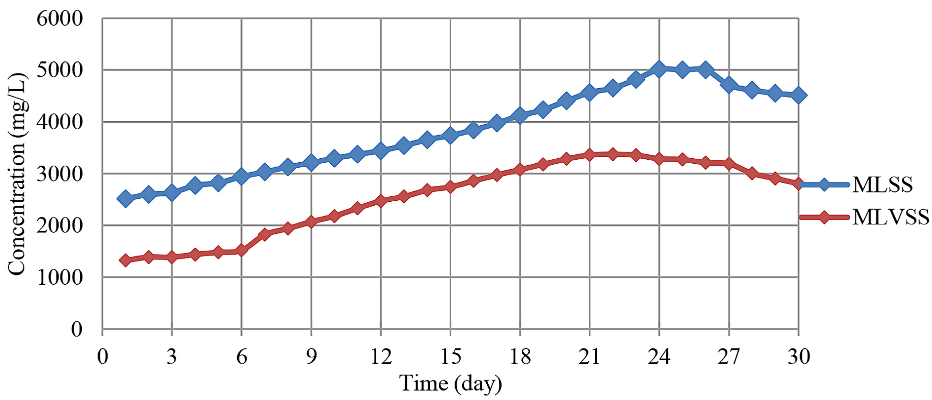


Figure 4. Temporal variation of MLSS and MLVSS concentrations during the start-up period of SBR

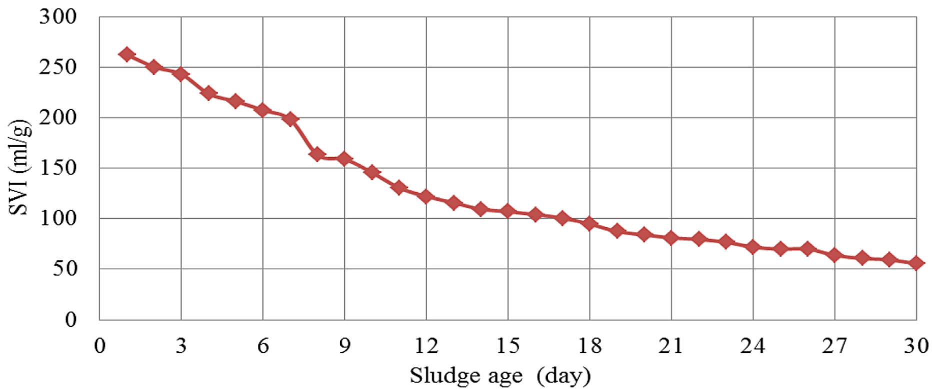


Figure 5. SVI versus sludge age during the startup period of SBR

SBR performance

According to the results of influent and effluent analyses, the removal percentages of COD, BOD, and oil and grease were obtained and they are presented in Figure 6. The figure shows that the removal efficiency values of COD, BOD, as well as oil and grease varied over the ranges (71.1–75.1), (81.9–85.0), and (66.7–68.4) %, respectively.

Figure 7 shows the efficiency of SBR in removing VSS and TSS. The VSS and TSS removal percentages vary over the ranges (57.5–81.2) (59.8–82.0)%, respectively. These results agree with those of Showkat and Najar (2019) who concluded that the SBR has low efficiency of suspended solids removal. The removal rate of NBSCOD and NBPCOD during the SBR

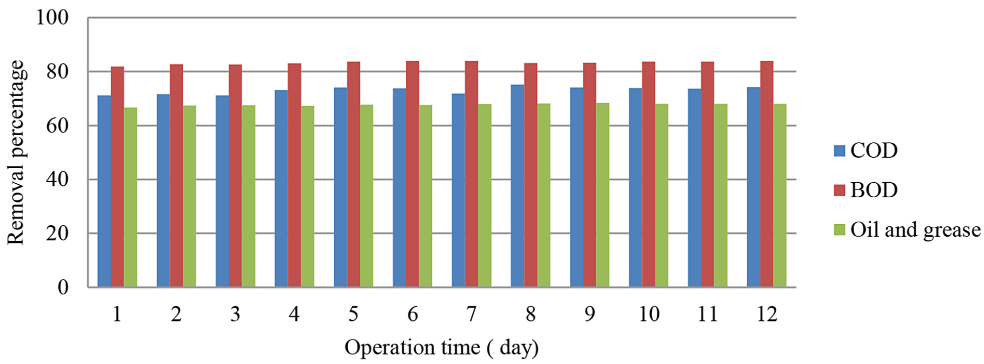


Figure 6. SBR removal efficiency of COD, BOD, and oil and grease

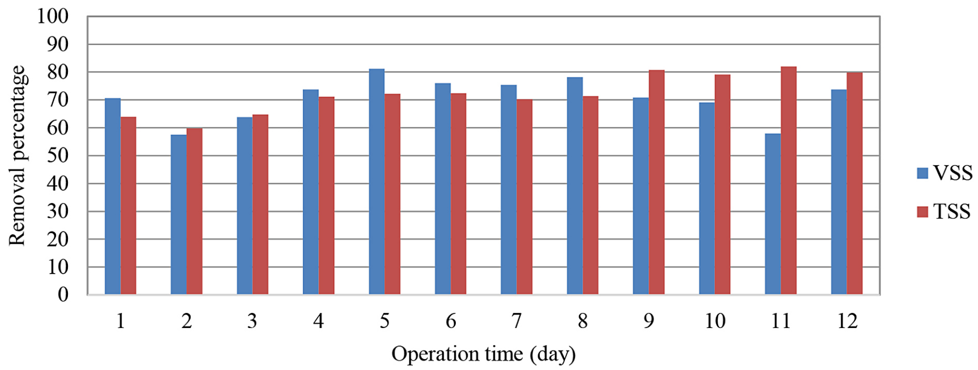


Figure 7. SBR performance: Removal of VSS and TSS

operation are shown in Figure 8 which indicates that the removal percentage of NBSCOD and NBPCOD vary of the range (63.8–66.5) and (53.8–75.5) %, respectively.

The variation of NBDSCOD and NBDPCOD in raw wastewater (influent) during the SBR operation period is shown in Figure 9. The values of NBDSCOD and NBDPCOD vary over the ranges (336–436) and (266–538) mg/L, respectively. Figure 9 illustrates that the soluble fraction of non-biodegradable COD may be greater or less than the particulate one. However, in 58.33% of the wastewater samples, the NBDSCOD fraction is greater than the NBDPCOD one. Thus the major part of the non-biodegradable organics is soluble that needed to remove from effluent, while, NBDPCOD represents 41.66% of non-biodegradable COD that can be trapped within the activated sludge and removed from the main wastewater stream by the settling.

The variation of effluent NBDSCOD and NBDPCOD during the operation period is shown in Figure 10. The values of NBDSCOD and

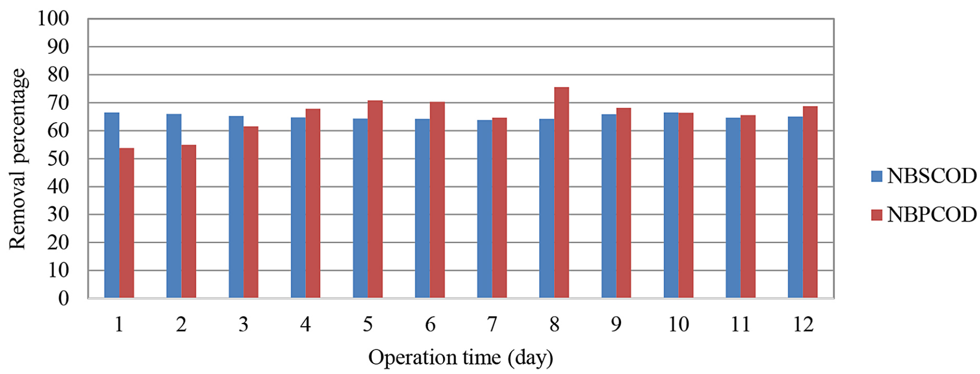


Figure 8. SBR performance: Removal of NBSCOD and NBPCOD

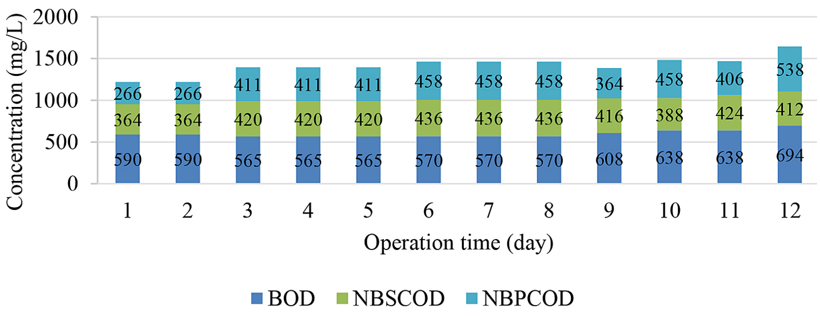


Figure 9. Characterization of influent COD during the SBR operation

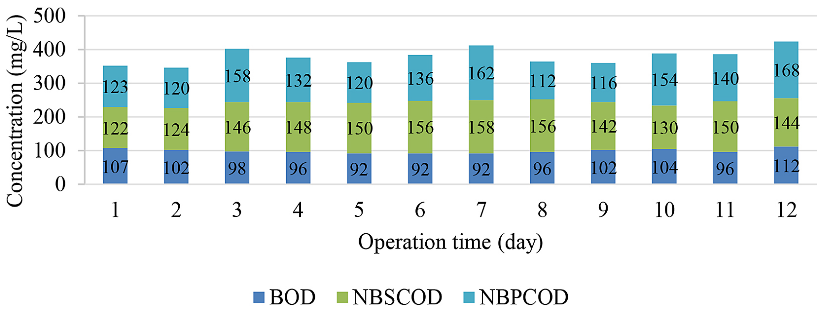


Figure 10. Characterization of effluent COD during the SBR operation

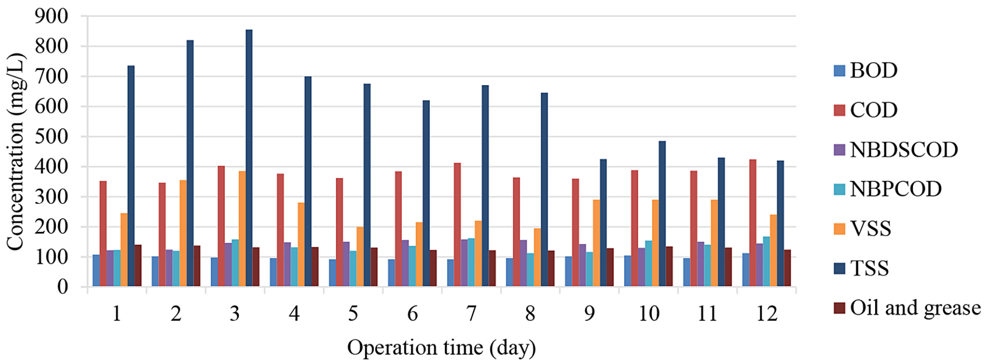


Figure 11. Variation of effluent BOD_5, COD, NBSCOD, NBPCOD, VSS, TSS, as well as oil and grease

Table 3. Compliance check of SBR effluent characteristics with the Iraqi regulations

Parameter	Unit	Ranges of measured values	Iraqi standard limits for wastewater discharge to surface water bodies
BOD	mg/L	92–112	<40
COD		346–424	<100
TSS		420–855	<60
VSS		195–385	–
Oil and grease		121–140	4
NBSCOD		122–158	–
NBSCOD		112–168	–

NBDPCOD vary over the ranges (122–158) and (112–168) mg/l, respectively, and as in the influent, the NBDSCOD fraction is greater than the NBDPCOD one.

The effluent characteristics (BOD_5, COD, NBSCOD, NBPCOD, VSS, TSS, as well as oil and grease) during the SBR operation are shown in Figure 11. The values range of each parameter was compared with its corresponding permissible limit of Iraqi regulations. The comparison results are presented in Table 3. It can be noticed from this table that the effluent BOD_5, COD, TSS, as well as oil and grease did not comply with the permissible limits required by Iraqi regulations. In turn, no Iraqi limits were reported for the VSS, NBSCOD, and NBPCOD.

CONCLUSIONS

The findings of the experimental study conducted on applying the SBR system for treating automotive services wastewater showed that the startup period is about 36 days. During this period, the MLSS and MLVSS concentrations gradually increased over time until the biomass growth reached a steady state in the period of (21–26) days, the maximum values of MLSS and MLVSS were 5012 and 3285 mg/l, respectively. In turn, at the time of maximum MLSS occurrence, the achieved SVI was 72 ml/g.

The SBR performance results showed that the removal efficiency values of COD, BOD, as well as oil and grease varied in the ranges (71.1–75.1), (81.9–85.0), and (66.7–68.4) %, respectively. The VSS and TSS removal percentages vary in the ranges (57.5–81.2) (59.8–82.0) %, respectively. The removal percentage of NBSCOD and NBPCOD vary of the range (63.8–66.5) and (53.8–75.5) %, respectively.

The comparison of effluent characteristics with their corresponding permissible limit of Iraqi regulations revealed that the effluent BOD_5, COD, TSS, as well as oil and grease did not comply with the permissible limits required by Iraqi regulations. Accordingly, it was concluded that the SBR system used to treat the oily wastewater generated by automotive services needs to be improved by adding innovative technologies to comply with the permissible limits required by standard specification regulations.

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