



Modelling and parameter optimisation for performance evaluation of sequencing batch reactor for treating hospital wastewater

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Abstract

Hospital wastewater treatment is gaining attention in recent studies due to its complex nature. The performance of the sequencing batch reactor coupled with tube-settler was investigated for hospital wastewater treatment. The performance was evaluated regarding removing organic matter and nutrients (nitrate and phosphate). The phosphate was removed in the sequencing batch reactor and its associated tube-settler with a 60% removal efficiency margin. Nitrification was observed in sequencing batch reactor and tube-settler, but denitrification could not be achieved. The nitrification–denitrification process was not completed during the process. The current work's main aim was to understand and optimise the operational parameters involved in the performance of the sequencing batch reactor. The operational parameters were optimised using Design expert software, and Response Surface Methodology involved a four-factor and five-level central composite design. The percentage removal of chemical oxygen demand, nitrate, and phosphate was selected to be observed during this study.

Keywords Hospital wastewater · Sequencing batch reactor · Tube-settler · RSM modelling · Organic matter · Nutrients · Kinetics

Highlights

1. Performance of SBR and tubesettler is discussed for hospital wastewater.
2. Optimisation of the operational parameters of sequencing batch reactor has been elaborated.
3. RSM modelling is performed considering four factor and five level central composite design.
4. Most sophisticated results have been observed in terms of organic matters and nutrients removal.

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Nomenclature

COD	Chemical oxygen demand (mgL ⁻¹)
BOD	Biochemical oxygen demand (mgL ⁻¹)
MLSS	Mixed liquor suspended solids (g/L)
SVI	Sludge volume index (mL g MLSS)
AOX	Adsorbable organics halides (mgL ⁻¹)
SBR	Sequencing batch reactor (no unit)
ASP	Activated sludge process (no unit)
MBR	Membrane bioreactor (no unit)
HRT	Hydraulic retention time (h)
CCD	Central composite design (no unit)
RSM	Response surface methodology (no unit)
LC-MS	Liquid chromatography and mass spectroscopy (no unit)

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GAC	Granular activated carbon (mm)
ds/dt	Change of substrate concentration with respect to time
Q	Flow rate
V	Volume of the reactor
S _o	Initial substrate concentration
S _e	Final substrate concentration
K ₁	First-order rate constant
K ₂	Second-order rate constant
K _s	Maximum substrate utilisation rate
K _B	Saturation value constant
U _M	Maximum substrate utilisation rate
R ²	Correlation coefficient
F/M	Food to microorganism ratio

1 Introduction

The quantum of wastewater generated from hospitals is mammoth and causes a significant threat to the environment and human health [1]. The effluent generated from hospital units such as pathological laboratories, infectious wards, and staff accommodation is very complex since it contains pathogenic microbes, drug residues, chemicals, biological tissues, cultures, chemical toxins, etc. [2]. Some potential implications of untreated hospital effluent include microbial resistance, genotoxic and teratogenic effects, toxic effects, ecotoxicity, DNA damage, persistence, bioaccumulation, etc. [3]. Hospital wastewater has recently gained attention due to pharmaceuticals and antibiotic compounds in high concentrations [4]. Hospital wastewater is very harmful when entered into any ecosystem untreated and causes a threat to the existing ecosystem [5]. Upon entry into the environment, pharmaceutical compounds threaten the ecological balance of microorganisms, especially antibiotics. The residues antibiotic resistance among bacteria. This leads to the development of antibiotic resistance genes in bacteria. This, poses a threat to ecological risk besides being a risk to animals and humans. The anti-resistance genes propagate widely in horizontal gene transfer and are introduced in various habitats. This is a severe risk as even upon the death of the resistant bacteria, its resistance genes would be released into the ecosystem, which another microorganism can assimilate, and several studies have reported that these resistance genes can be transferred to humans and animals through food and water [7]. This necessitates the employment of effective treatment technology for hospital wastewater treatment. The sequencing batch reactor (SBR) has successfully removed organic compounds and nutrients from wastewater. The SBR is a popular aerobic technique with several operational and performance advantages [8]. It has been reported that the aerobic treatment proved to be more economical and has better sludge conditions and adaptability toward shock loading [9].

SBR has been investigated for biological treatment, nitrification, denitrification, and phosphorous removal from wastewater [6]. SBR has a wide range of applications in wastewater treatment. Its performance has been investigated in many research works for the treatment of low-strength municipal wastewater [7], pulp and paper mill wastewater [8], brewery wastewater [9], landfill leachate and dairy wastewater [10], textile wastewater [6], low salinity shrimp aquaculture wastewater [11], and nylon wastewater [12]. The challenge came with the arrival of COVID-19 [13] and following up world vaccination campaign, which was on a large scale carried out in hospitals as well [14], pandemic agro-industry wastewater [15], duck house wastewater [16], and petroleum refinery wastewater [17]. SBR performance was also investigated for specific constituents, e.g. levofloxacin, high strength N-methyl-2-pyrrolidone [18], 2,4 dichlorophenol and opium alkaloid (gamma radiation) [19]. Several studies have focused on the removal of pharmaceutical compounds from wastewater. The literature is also available based on synthetic sewage [20]. Most of the research works were carried out using synthetic lab-made pharmaceutical wastewater. The research on organic matter and nutrient removal from hospital wastewater need more attention. The organic matter and nutrients still govern the design of wastewater treatment plants [21]. The current study has been focused on addressing the identified research gap.

The current work was carried out on treating wastewater from the hospital using SBR combined with a tube-settler for organic matter and nutrient removal [14]. The tube-settler was in coherence with the existing wastewater treatment plant installed at the hospital. The literature based on employing SBR for hospital wastewater treatment is lacking [15]. Tubesettler has been used with aerobic fixed film bioreactor, electro bioreactor, constructed wetland, and fluidised bed bioreactor for hospital wastewater treatment [16]. Table 1 presents the literature pertaining to the type of wastewater treated using SBR and tube settler. It can be observed from Table 1 that SBR has not yet been explored for hospital wastewater treatment.

Also, any study combining tubesettler with SBR is yet to be investigated for hospital wastewater treatment. The novelty of the study comprises employing SBR for hospital wastewater treatment. Also, combining tubesettler with SBR is one of first of its kind of study per the author's information to be reported. The main aim of the current work was to understand and optimise the operational parameters involved in the performance of the SBR. The treatment of hospital wastewater (HWW) was enabled to understand and meet the local discharged limits laid by various regulatory authorities. The operational parameters considered during this experiment were optimised using Design expert software, a four-factor and five-level central composite design involved by RSM. The percentage removal of COD, nitrate, and phosphate was selected to be observed because physical parameters are controlled and optimised in the current study.

The different selected parameter during the study was initial COD concentration, and mixed liquor suspended solids (MLSS),

Table 1 Literature on the treatment of wastewater using SBR and tubesettler

Type of wastewater	Primary treatment	Associated pre/post-treatment	Reference
Hospital wastewater	Constructed wetland	Tubesettler	[14]
Hospital wastewater	Aerobic fluidised bed bioreactor	Tubesettler	[15]
Hospital wastewater	Extended aeration	Tubesettler	[17]
Hospital wastewater	Electro-bioreactor	Tubesettler	[18]
Hospital wastewater	Membrane bioreactor	–	[19]
Hypersaline mustard wastewater	Sequencing batch bioreactor	–	[20]
Industrial wastewater	Sequencing batch reactor	Photocatalytic-oxidation	[21]
Textile wastewater	Sequencing batch reactor	Nano-filtration	[22]
Industrial wastewater	Sequencing batch reactor	Advanced oxidation	[23]
Low-strength saline wastewater	Sequencing batch reactor	–	[24]

cycle time, and initial pH of the influent. The SBR performance was evaluated after optimisation through (Fig. 1):

- (i) Organic matter removal in terms of COD and BOD,
- (ii) Nutrients removal Nitrate and Phosphate and
- (iii) Comparison of SBR results with uncoupled tube-settler for removal efficiency.

2 Method and material

2.1 Experimental setup and operation

In the presented work, the laboratory-scale sequencing batch reactor (SBR) was fabricated with perspex material and had a

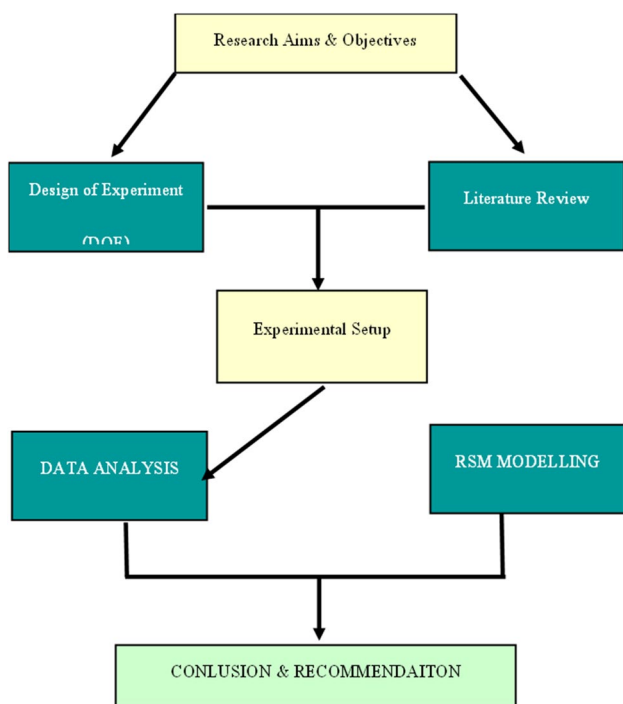


Fig. 1 Flow chart of the methodology adopted in the present study

total volume of 3.46 L in Mewat Engineering College, Nuh. The schematic diagram of SBR coupled with tube-settler is shown in Fig. 2a. Figure 2b shows the before and after treatment sample quality. The reactor was 7 cm in diameter and 90 cm in height. One air pump system, model EK- 8000, 6 W, was used for supplying diffused air to the reactors. The entire experimental setup was automated with a solenoid valve and gate valves followed by automatic on–off timers with different time-dependent cycles. A tank of 12-L capacity was provided for the influent of the SBR. A tube-settler was employed in series to provide more retention time and enhance pollutant removal efficiency.

Tubesettler provides an efficient option as a polishing unit for effluent or replacement as a secondary clarifier. Hospitals are located within urban landscapes, which comes one big obstacle in the installation of wastewater treatment units in hospitals, i.e. space. Tubesettler being compact compared to sedimentation or clarifier tanks provides an economical and economical solution to the problem of space experienced in an urban environment.

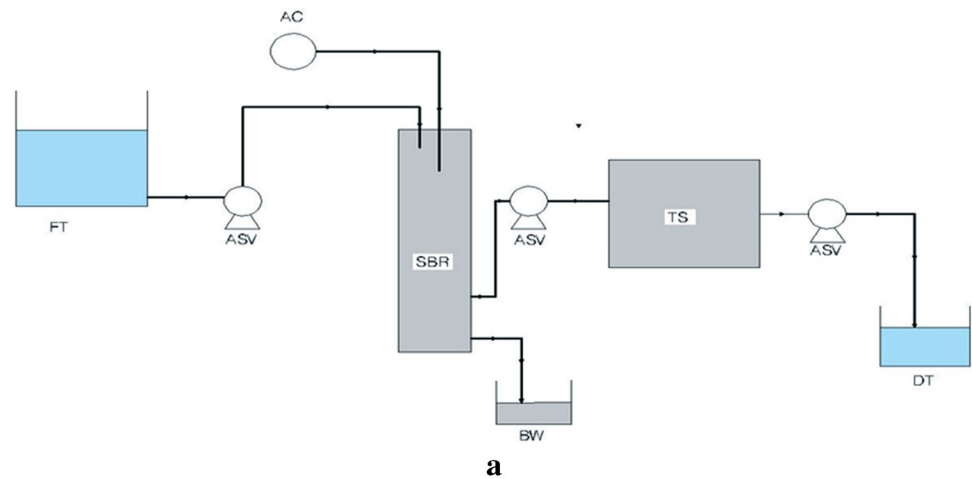
The research methodology adopted in this study is presented in Fig. 1.

A tubesettler was used in series with an SBR setup (Fig. 2). Effluent from SBR was introduced as an influent to tubesettler for further removing pollutants from wastewater. A tubesettler was linked to SBR of dimension 30 cm × 30 cm. A tubesettler consisted of 30 cm oblique length. The thickness of the pipe was 0.4 mm with a specific surface area of 139 m². The angle of inclination for the tubesettler pipe was 60°. The velocity was controlled between 2.5 and 3 mm/s.

2.2 Seeding and influent wastewater

Hospital wastewater collected from Shaheed Hassan Khan Mewati Government Medical College, Nalhar, Mewat, India, was used in this experiment. The seeding and influent wastewater comprised of collected wastewater from the hospital to present real-time performance of the setup and determine the elements affecting its performance. The wastewater was collected

Fig. 2 a Schematic diagram of SBR setup coupled with tube-settler (AC; air compressor, FT; feed tank, ASW; automated solenoid valve; SBR; sequencing batch reactor, TS; tube-settler, DT; decant tank and BW; biomass wasting). **b** Sample collected from the hospital before and after treatment



as grab composite samples over 24 h at 4 h intervals, which led to 6 samples for a period of 34 weeks starting from 25th Aug 2021 to 20th April 2022.

The wastewater samples were collected from the effluent pipe leading to the wastewater treatment plant of the hospital. The wastewater samples were obtained and collected amber colour glass bottles. The collected wastewater samples were stored at 4 °C before their analysis. All the collected wastewater samples were analysed within 24 h of collection time. The composition of wastewater used in this study is presented in Table S1. The removal efficiency was calculated as per Eq. 1, as given below.

$$\text{Removal efficiency (\%)} = \frac{(\text{influent concentration} - \text{effluent concentration})}{\text{influent concentration}} \times 100 \quad (1)$$

2.3 Analytical methods

Grab samples were obtained from the influent and effluent of SBR and tube-settler setup. Biological oxygen demand, chemical oxygen demand, nitrate, and phosphate concentration were determined per standard methods [22]. The

parameters such as pH, MLSS, nitrate, and phosphate test were conducted per the standard method for experimental analysis [22].

2.4 Operational parameters

At starting, the reactor was fed with diluted 1 in 10 with the hospital wastewater. After 15 days, the concentration was fed with less dilution, as 1 in 7 and 1 in 5, and 1 in 3 successfully with a similar period gap. As per

observation, acclimatisation was achieved in the reactor environment, after which wastewater was fed to the reactor. The typical characteristic of HWW obtained is presented in Table S1. The experimental process with variation in the cycle duration observed from 24 to 8 h is presented in Table S2. The duration of different phases of SBR operation is shown in Table S3.

2.5 Experimental process design using RSM

The optimisation of different process parameters using a Design Expert (version 13.0) was used during this study. The method employed for optimising these types of systems is best suited to the RSM method. In this, the independent operation parameters can be optimised to reduce the experimental cost and physical labour. These approaches also help us to understand the nature and dependencies of each operation parameter on each other. The Central Composite Design (CCD) was selected with a sequential sum of squares test, and a lack of fit test was used. The CCD model was chosen to observe the relationship between the selected process parameters (independent variable) such as initial COD concentration, MLSS, pH, and the cycle duration, thereby observing its effect on the response parameters like COD phosphate and nitrate removal. The software was employed for the optimisation process, and the four-factor and five-level CCD system was adopted during the 30 experiments. In the experiment, the process was trained for the 16 factorial points, 8 axials, and 6 central points, which were considered to observe the response to process parameters in the RSM model. The independent variable selected for this study is illustrated in Table 2. The model chosen in response to the process parameter optimisation was used in this study, and the quadratic equation model in CCD was best suited for this experimental study.

Table 2 Process variables in modelling with RSM

Coded values	A: COD initial (mg/L)	B: MLSS (mg/L)	C: Cycle time (h)	D: pH
-2.0	100	1,000	6	4.5
-1.0	200	1,500	12	6.5
0.0	300	2,000	18	8.5
1.0	400	2,500	20	10.5
2	500	3,000	24	12.5

Table 3 Kinetic modelling for wastewater concentration and removal efficiency after optimisation [26]

Kinetic parameter observed	Model analysed	Kinetic parameters observed during the study		R ² value
COD	1 st order	$K_1 = 1.393$	—	0.651
	Grau 2 nd order Model	—	$K_s = 10^{-05}$	0.9626
	Modified Stover-Kincanna model	$K_B = 0.378$	$U_M = 2.45$	0.9518
	Monod Model	$K = 0.045$	$K_s = 0.056$	0.951

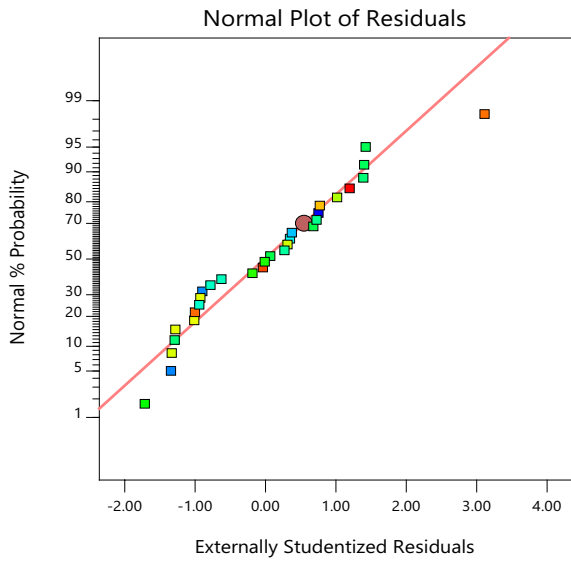
2.6 Kinetic modelling

Attached growth processes generally offer higher biomass concentrations (with a greater specific surface area) over suspended growth in smaller reactor volumes and shorter HRTs. The transfer of substrates to the biofilm, both electron donor and acceptor, is more complicated. Using biofilm dynamics, it could be understood how fast microbes remove the substrate and what factors influence transport in microbial films. Keeping biofilm alive during wastewater treatment is critical to delivering substrates to the cells. A concentration gradient in the substrate is created when cells congregate. The kinetics of substrate removal in biofilm applications depends on the wastewater substrate concentration. The kinetic description has been investigated, evolving from a first-order expression at low doses to a zero (0⁰) order expression at extremely high concentrations. There were many models used for the physical system. Still, we have adopted only three models for our study to get in-depth knowledge as well as understand the kinetics of the biological system. The 2nd order seems to be best suited for the said study. A change in substrate concentration has been represented from very low to extremely high; a half (0¹) order is used for low substrate concentrations. The kinetics of process parameters, such as COD removal, nitrate, and phosphate for the experiment, was also studied using the first-order model, Grau second-order model, modified Stover–Kincannon model, and Monod model. The well-established kinetic model was used to study water and wastewater using biological treatment systems. The study was done when the system was steady after acclimatisation. Table 3 presents the kinetic models applied in this study.

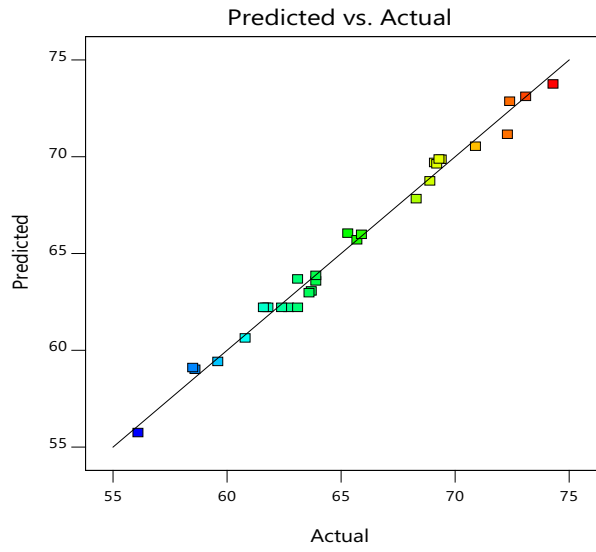
3 Results and discussion

3.1 Polynomial regression model for removal efficiency

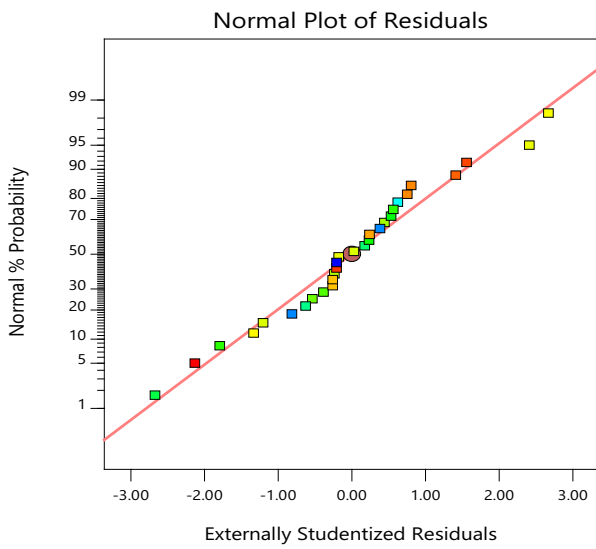
The output and process parameters were judged from diagnostics as predicated values versus the actual plot. It has



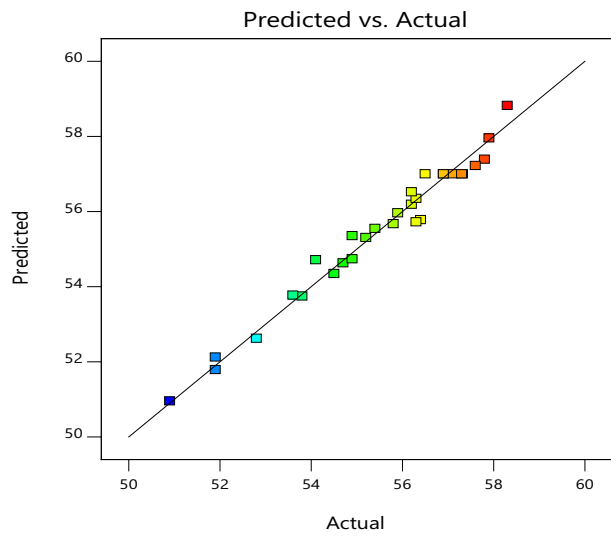
a



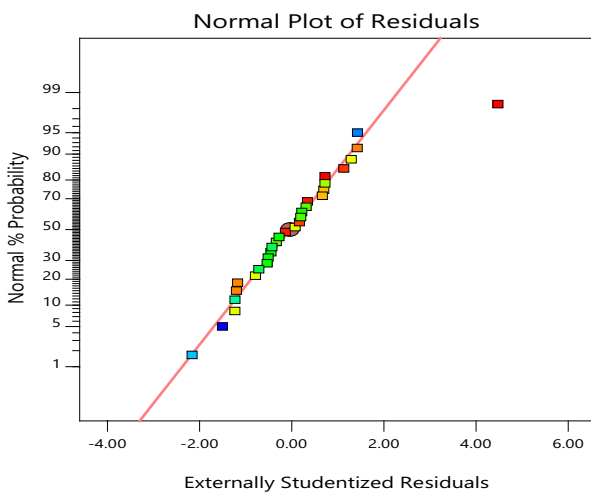
b



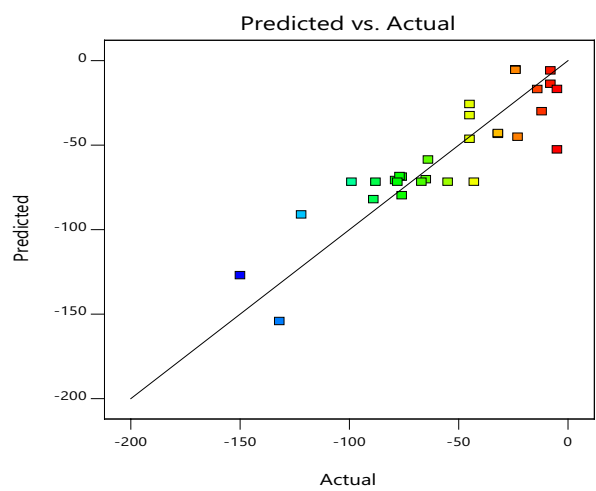
c



d



e



f

Fig. 3 Modelled graphs of normal probability with respect to studentised residuals (a, c, e) and predicted values with respect to the actual COD removal, nitrate removal, and phosphate removal (a, b, c, d, e, f)

been observed that the model shows quadratic polynomial equation much more satisfactory results and can be seen in the diagnostic plots shown in Figs. 3, 4, 5.

The following polynomial regression model equations were obtained using RSM clubbed with CCD:

$$\begin{aligned} \text{COD removal \%} = & 62.2 - 3.0 * A + 2.0 * B - 0.75 * C + 2.7 * D + 0.6 * AB + 0.2 * AC + 0.5 * AD + 0.08 * BC + \\ & 0.28 * BD + 1.0 * CD + 0.7 * A^2 + 1.8 * B^2 + 0.5 * C^2 + 0.69 * D^2 \end{aligned} \tag{2}$$

$$\begin{aligned} \text{Nitrate removal \%} = & 57.0 + 0.17 * A - 0.7 * B - 0.20 * C + 0.14 * D - 0.725 * AB + 0.3 * AC - 0.18 * AD + 0.2 * BC - 0.38 * \\ & BD + 0.8 * CD - 0.03 * A^2 + 0.06 * B^2 - 1.40708 * C^2 - 0.49 * D^2 \end{aligned} \tag{3}$$

$$\begin{aligned} \text{Phosphate removal \%} = & -71.6 - 2.83 * A - 0.5 * B - 3.41 * C - 13.5 * D - 16.6 * AB + 8.6 * AC + 9.1 * AD + 21.25 * BC + \\ & 18.25 * BD - 14.5 * CD + 15.12 * A^2 + 0.5 * B^2 - 0.87 * C^2 + 4.75 * D^2 \end{aligned} \tag{4}$$

where A = initial COD (mg/L)
 B = MLSS concentration (mg/L)
 C = Cycle time (h), and
 D = pH

3.2 Chemical oxygen demand

The influent and effluent COD concentration of SBR and removal efficiency are presented in Fig. 6. The average effluent concentration was 44 mg/L. With an increase in time for the SBR setup, the effluent concentration resulted in a decreasing trend. During the first four weeks, effluent concentrations were 54 and 56 mg/L, which decreased to an average concentration for the other four weeks to 39 mg/L and, in the final four weeks, reduced to 31 mg/L. The improved quality of effluent can be attributed to the maturity and stabilisation of the setup for treatment. The influent concentration had a standard deviation of 76 mg/L, and the removal efficiency was limited between 87 and 91%, which indicated consistency of SBR efficiency against variation of organic loading. The results coincide with other studies for treating various wastewater using SBR. 90% COD removal was reported from Brewery wastewater using SBR [9], residential and oil–gas wastewater 90.4% [23]. The higher removal efficiency using SBR for duck house wastewater, landfill leachate, and dairy wastewater was 98% [16].

Tube-settler influent and effluent COD concentration with removal efficiency was presented in Fig. 6. The overall COD removal efficiency is shown in Table 4. Tube-settler resulted in a higher concentration in weeks 1–8 of 44 mg/L but decreased to an effluent concentration of 32 mg/L, and the coming 9–12 weeks and the final four weeks produced effluent with a COD concentration of 24 mg/L. This reduction in the last eight weeks can be attributed to high-quality effluent from the SBR setup, which rationally decreased the COD concentration in tube-settler effluent. The COF

removal efficiency was lower in tube-settler ranging between 16 and 20 mg/L.

The *p*-value (*p* < 0.02) infers a slightly significant difference in effluent concentration for COD from SBR. The tube-settler results did not exhibit a significant difference (*p* < 0.001).

The developed model from experimental data accuracy was validated using analysis of variance (ANOVA) [24]. Statistical indices like *P*-value and *F*-value are obtained from ANOVA. The small *P*-value (0.05) with a large *F*-value is considered statistically significant. A high correlation coefficient value also infers the accuracy of the proposed model.

Using two variables and keeping one fixed, 3-D plots were developed. The removal efficiency was obtained as per the 3-D graph presented in Fig. 6. At a cycle time of 15 h, the effect of MLSS and COD concentration is illustrated in Fig. 5. The 88.7% COD removal was achieved at an MLSS concentration of 2000 mg/L. In contrast – 150% and 93% were reached for nitrate and phosphate. The increase in initial COD concentration caused a decrease in microbial [33] activity due to organic overloading. With an increase in MLSS, concentration removal efficiency also increased Fig. 4. This was due to higher contact time with biomass at higher MLSS concentration, causing higher degradation.

The decrease in cycle time from 24 to 12 h depicted a reduction in removal efficiency of COD owing to reduced contact time with biomass. Figure 6 shows with MLSS concentration up to 3000 mg/L, COD removal of up to

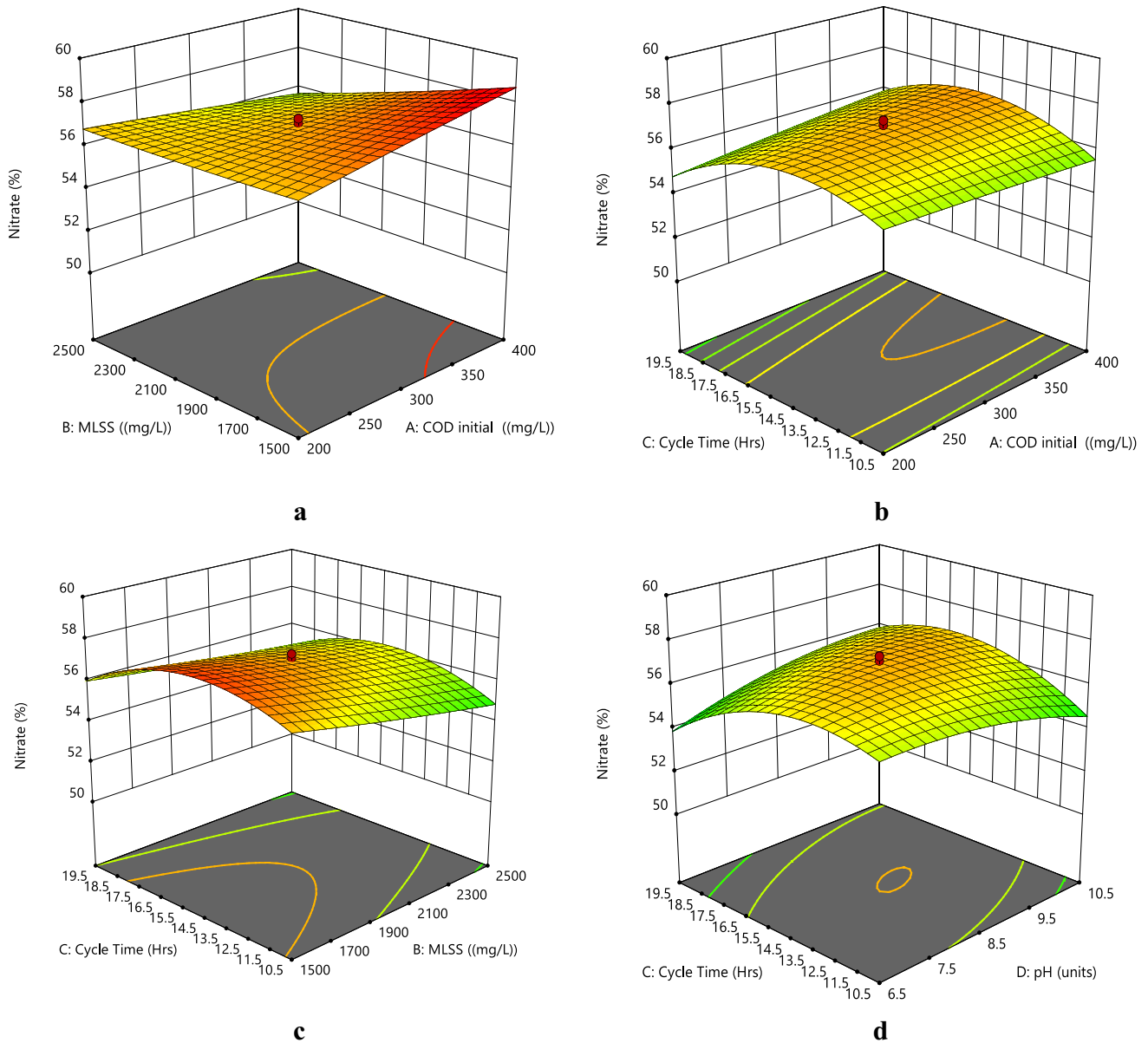


Fig. 4 Surface plot obtained from RSM model having output parameter as nitrate removal (a) MLSS with respect to initial COD. (b) Cycle time with respect to initial COD. (c) Cycle time with respect to MLSS. (d) Cycle time with respect to pH

88.3% can be achieved concerning constant initial COD, which can be attributed to higher microorganism availability in the reactor. The pH of the reactor directly affects the granule formation. As pH shifts from acidic to basic, COD removal efficiency is shown in Fig. 6. The pH 8.5 provided an optimum range for bacterial growth to induce granule formation, as an acidic range of pH would result in the development of fungi. The formulation of granules in various operating phases of SBR is illustrated in Fig. 7. At 100 days, it was observed that small biomass [32] granules were in circulation. There was a remarkable increase in granulation up to 100 days.

3.3 Biological oxygen demand

The BOD_5 effluent concentration was consistent irrespective of incoming influent, as presented in Fig. 8. The removal efficiency had a standard deviation of 2.3 mg/L. The average removal efficiency was 87% which was also observed in the case of COD. The consistent effluent concentration compared to COD indicates the presence of other elements affecting the removal efficiency. The BOD_5 removal efficiency was lower than other studies treating wastewater using SBR. The study treating duck house wastewater reported 99% removal, the landfill leachate,

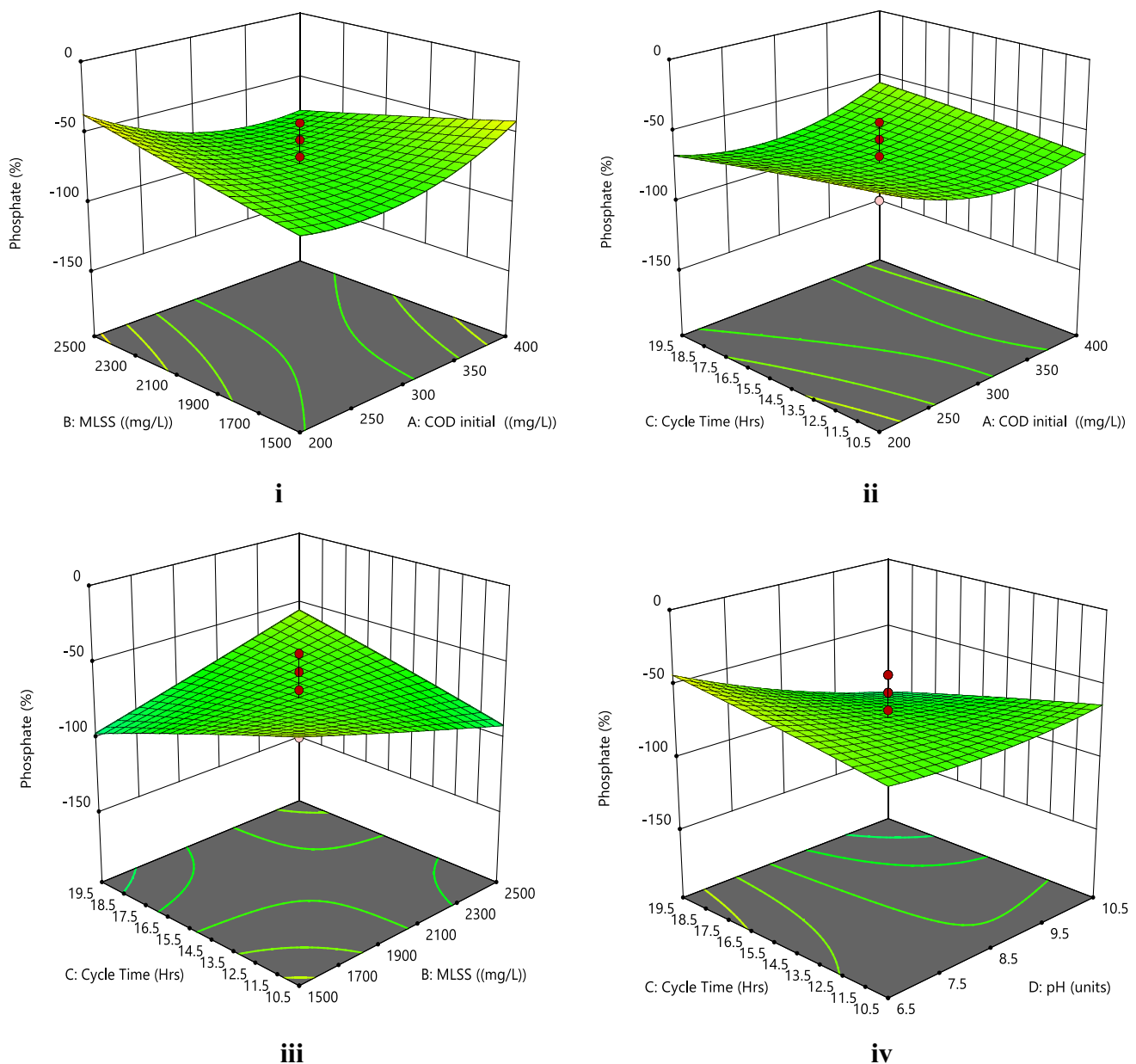


Fig. 5 Surface plot obtained from RSM model having output parameter as phosphate (i) MLSS with respect to initial COD. (ii) Cycle time with respect to initial COD. (iii) Cycle time with respect to MLSS. (iv) Cycle time with respect to pH

the dairy wastewater study reported 98% removal, and the complex chemical wastewater reported 93% [24]. The Brewery wastewater reported an 80% reduction in BOD_5 , lower than the efficiency found in this study [25].

The tube-settler followed a similar consistency as the SBR setup. The SBR effluent was already under standard permissible BOD_5 discharge limits. The removal efficiency was low, but the lower concentration in the effluent may have affected the removal efficiency, which was observed to range between 14 and 18%, as presented in Fig. 9.

The BOD concentration results in the SBR effluent exhibited a significant difference ($p > 0.05$). While in this aspect, tube-settler was performed with consistency ($p < 0.001$).

3.4 Nitrate

High organic loading conditions limit the nitrification process since oxygen was used to consume organic matter. Nitrification and denitrification are primarily

Fig. 6 COD concentration in influent, effluent and removal in mg/L (SBR)

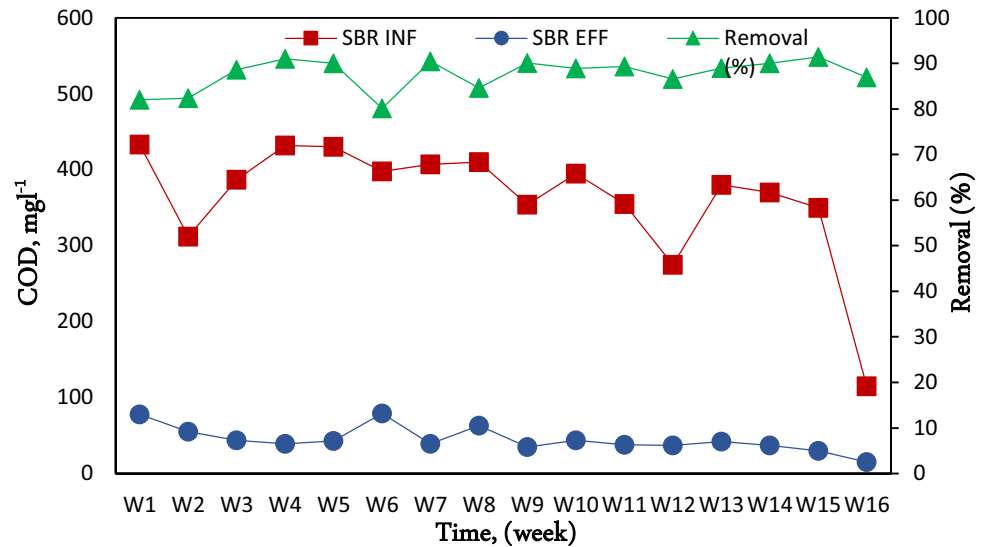
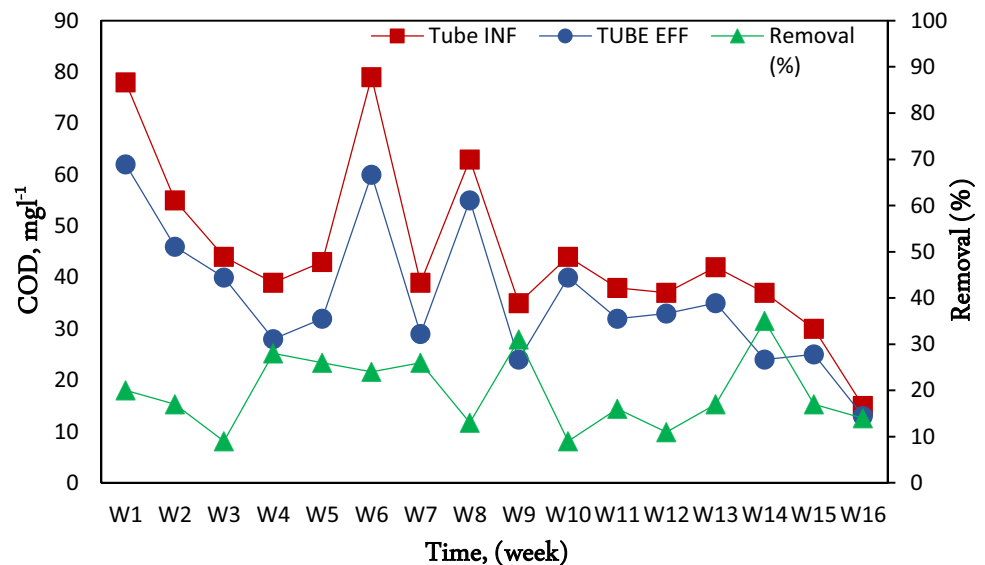


Table 4 SBR and tube-settler effluent wastewater concentration and removal efficiency after optimisation (mgL^{-1})

Parameter	SBR				Tube-settler				Overall Removal (%)	Optimised results Removal (%)
	Range	Mean	Std. deviation	Removal (%)	Range	Mean	Std. deviation	Removal (%)		
COD	15–79	44	± 16	87	13–62	36	± 13	20	89	85
BOD ₅	8–16	11	± 2.3	87	7–12	9	± 1.5	17	89	84
Nitrate	2.3–5.8	3.9	± 1.02	–109%	2.8–6.7	4.74	± 1.04	–20	–150	–142
Phosphate	2.4–5	3.5	± 0.79	85	0.35–1.4	0.46	± 0.29	85	93	92

Fig. 7 COD concentration in influent, effluent, and removal in tube-settler



controlled through DO concentration and an alternative cycle of aerobic and anoxic conditions in the reactor [25]. It is clear from Fig. 10 that nitrate concentration can be observed to be increasing in the effluent as compared to influent concentration. The range of increase

was between 87 and 130%. This indicates that the conditions in the SBR setup were suitable for nitrification. The increased concentration stated the presence of Nitrosomonas and Nitrobacter, the nitrifying bacteria. The negative removal of nitrate has also been reported in other

Fig. 8 BOD₅ concentration in influent, effluent, and removal in mg/L SBR

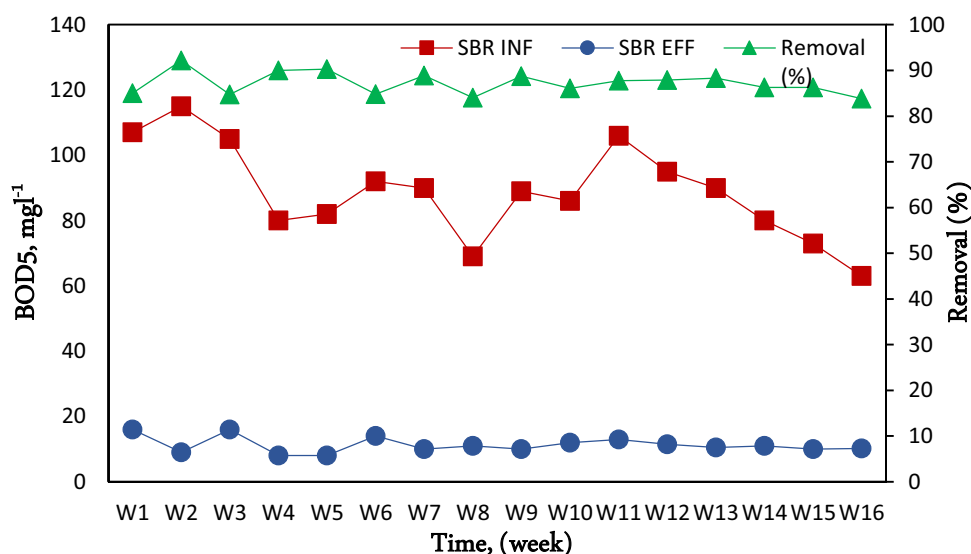
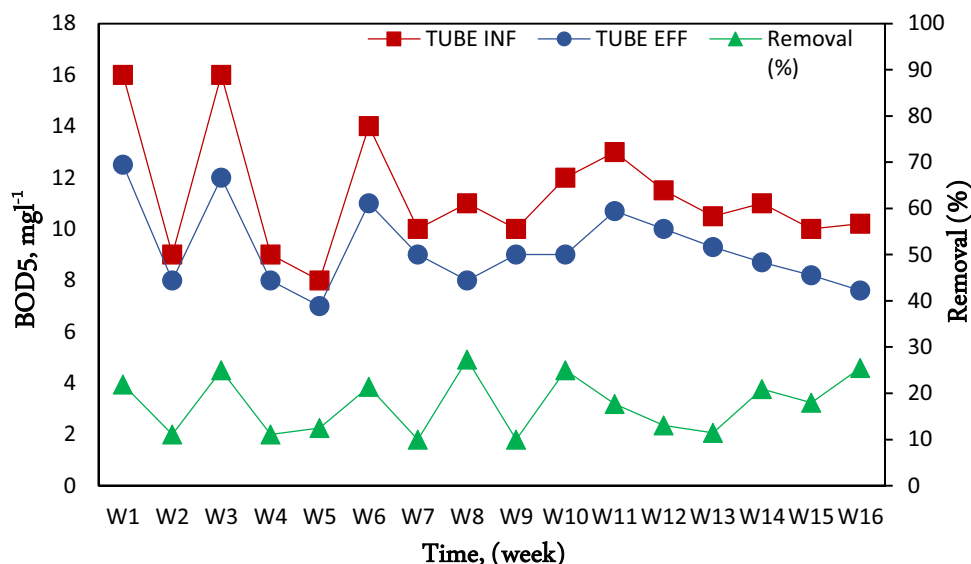


Fig. 9 BOD₅ concentration in influent, effluent, and removal in tube-settler



studies treating low salinity shrimp aquaculture wastewater by a 266% increase [11] and in duck house wastewater by 90% [16]. A 24% reduction in nitrogen concentration has been reported using SBR for treating combined residential and oil–gas sewage [23]. The Tapioca wastewater treatment using SBR has shown a 60% nitrogen reduction in the effluent. Since nitrification was observed, the SBT was well aerated due to the absence of denitrification, indicating anaerobic conditions did not exist in the SBR setup [25]. Tube-settler also demonstrated similar results in Fig. 11. An increase in nitrate concentration was not as high as in SBR. The nitrate concentration in the effluent was between 18 and 23% increase.

The results of nitrification for SBR have been found to have less difference ($p < 0.02$), and tube-settler results for

nitrification followed the trend of no significant difference ($p < 0.001$).

3.5 Phosphate

Phosphate removal can be achieved through biological treatment, physio-chemical methods, and combination. The biological treatment was a cost-effective and sustainable option compared to chemical treatment. Figures 12 and 13 showed phosphate influent and effluent concentrations in SBR and tube-settler. Table 4 presents the statistics description of effluent from SBR and tubesettler. Both processes reduced phosphate concentration in wastewater. The phosphate concentration in effluent from SBR and tube-settler was consistent and ranged between

Fig. 10 Nitrate concentration in influent, effluent, and removal in SBR

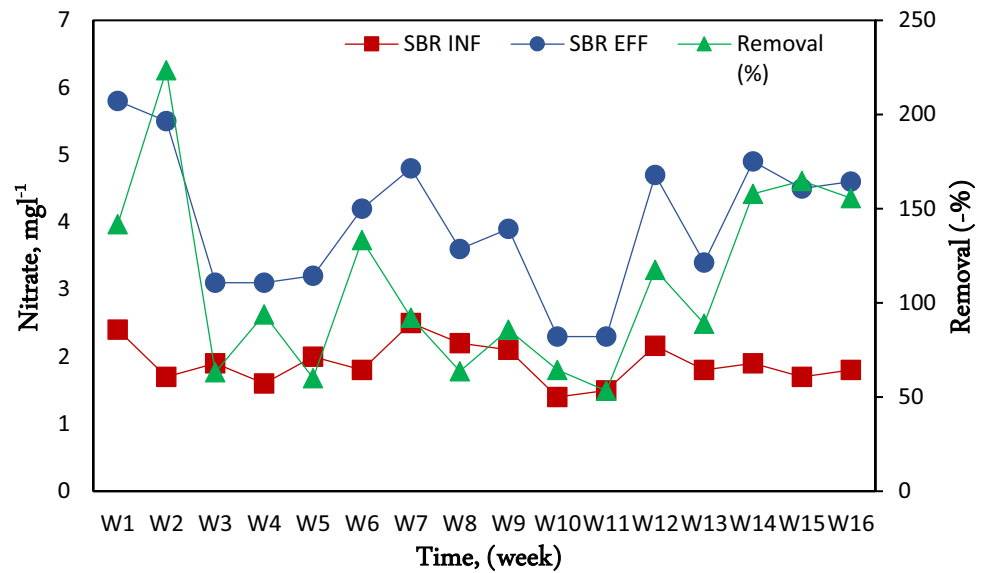
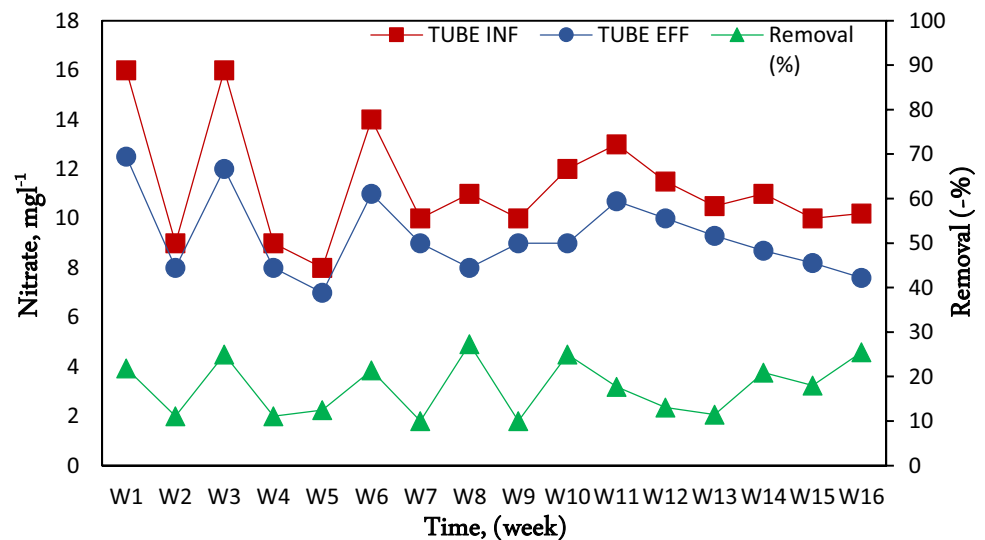


Fig. 11 Nitrate concentration in influent, effluent, and removal in tube-settler



3.05–4.07 mg/L and 1.3–1.48 mg/L. The removal efficiency of 57% was exhibited in SBR. The tube-settler achieved a slightly higher reduction at 61%. As per the reported result, phosphate removal using SBR varied greatly in reduction capacity. The phosphate reduction was 91% when treated with duck house wastewater [16]. The phosphate reduction was seen at 9.7% in treating composite wastewater from residence and oil–gas refinery wastewater [23]. The results were found in between the effects of both studies. This was because hospital wastewater [27] has both organic and pharmaceutical elements [28]. The oil–gas wastewater was high in chemical/inorganic loading, unlike high organic loading from duck house wastewater. The results are incoherent in both studies. The statistical analysis of phosphate depicted good consistency in effluent concentration for SBR and tube-settler ($p < 0.001$).

3.6 Combined removal efficiency of SBR and tubesettler

The removal efficiency of SBR in combination with tube-settler is presented in Table 4. The COD was removed up to 89% with combined treatment of SBR and tubesettler in this study. The removal efficiency of COD from hospital wastewater has been observed to be 95% in combination with constructed wetlands and tubesettler [14]. Eighty-five percent removal efficiency of COD was reported for treatment of hospital wastewater using an electro-bioreactor in combination with a tubesettler. [18] Another study investigating hospital wastewater treatment using fluidised aerobic bed bio-reactor in combination with tubesettler has reported 80–85% COD reduction. [15] BOD₅ removal from hospital wastewater was similar to COD, with 89% efficiency.

Fig. 12 Phosphate concentration in influent, effluent, and removal in SBR

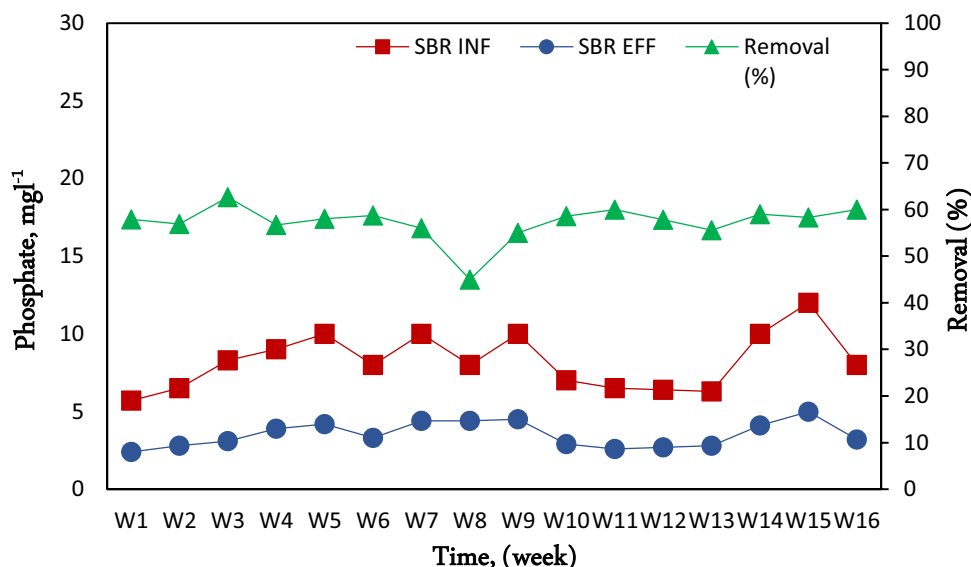
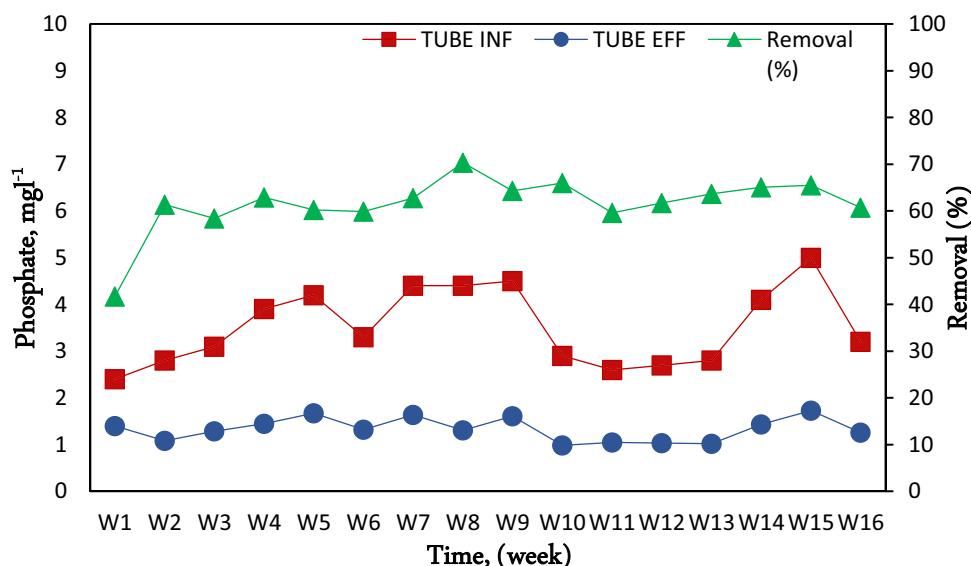


Fig. 13 Phosphate concentration in influent, effluent, and removal in tube-settler



Constructed wetland with a tubesettler has been reported to remove BOD₅ up to 97% [14], and an electrobioreactor with a tubesettler has been found to remove BOD₅ with an efficiency up to 85%.

The higher removal of COD and BOD₅ in a constructed wetland can be attributed to uptake by plants and absorption by sediments which two are absent in the electrobioreactor and sequencing batch reactor resulting in lower treatment efficiency.

Nitrate removal [30] was accumulated in the experiment setup instead of reduction. Combined SBR and tubesettler accumulation reached up to 150%. In the study employing constructed wetland and tubesettler, 74% increase in nitrate has been reported. Also, an increase of up to 103% has been reported for fluidised aerobic bed bioreactor

in combination with tubesettler. Nitrate [31] has been removed between 50 and 60% when treated with an electrobioreactor combined with a tubesettler [18]. The studies reporting an increase in nitrate concentration have attributed to a lack of anaerobic conditions, which inhibits the denitrification process and thereby hinders nitrate removal from wastewater. Phosphate, on the contrary, was removed with an efficiency of 93%. A fluidised aerobic bed bioreactor combined with tubesettler has reported removal efficiency of 60–70% from hospital wastewater. Electro bioreactor with tubesettler has been said to successfully remove phosphate up to 75% from hospital wastewater [18]. Seventy to 80% efficiency has also been achieved for phosphate removal from hospital wastewater using constructed wetlands with tubesettler [14].

3.7 Kinetic models analysis post optimisation

Design-Expert software's RSM model helps to optimise the process parameters in the design space. In this system, the modelled values can be optimised, and the most suited values can be adjusted to align the experiment in practical terms. The input parameters were optimised for removing COD, nitrate, and phosphate. It has been observed that the output parameter shows an efficiency of around 89% and – 150%, and 93%. The experimental values obtained for the validation were also carried out for optimising the process parameters and are shown in Table 3. The output parameters show a close relationship with the experimental values in the RSM [29] model, which may indeed be applied in the optimisation of process parameters.

3.7.1 First-order model

A first-order linear model was used on the experimental data. Plotting $(S_0 - S_t)/S_0$ against HRT provided K_1 and R^2 . For COD, R^2 values were 0.651 with a constant value of 1.393. Based on the results, the obtained model did not fit well for either of the cases.

3.7.2 Grau second-order model

The results were plotted using $HRT / ((S_0 - S_t)/S_0)$ and HRT. The COD constant obtained was $K_s = 10^{-5}$, as shown in Table 3. The R^2 value of 0.96 suggests a good correlation coefficient. The obtained results were fitted well for AOX and COD.

3.7.3 Modified Stover–Kincannon model

Substrate utilisation rate expressed as organic loading in this model is widely used in biological reactor kinetic modelling of wastewater. The developed model can evaluate the performance of the biological system and estimate its efficiency based on the input parameters. The Kinetic constant K_B and U_{max} for COD were 0.378 and 2.45 g/L/d. The R^2 value was found to be 0.95 for the substrate removal plot in the case of COD and AOX.

3.7.4 Monod model

COD utilisation rate was obtained by plotting $VX/Q (S_0 - S_t)$ against $1/S_t$. The value of $1/K$ (0.1541) was obtained from the intercept, while the K_s/K value (1.445) was a slope of the line.

COD removal half-saturation values were 0.045 and 0.056 g/L. These values infer a high affinity of bacteria for a substrate. The R^2 value of 0.95 depicted an excellent

correlation coefficient in the case of COD. The obtained constant values are presented in Table S1.

4 Conclusions

Hospital wastewater is complex compared to industrial wastewater, pertaining to various activities that change the volume and characteristics of wastewater. This study addressed the existing research gap concerning hospital wastewater treatment potential through SBR. This paper employed SBR connected with tubesettler to remove organic matter and nutrients from hospital wastewater. The BOD and COD removal efficiency was 87%. Nitrate concentration increased by 109% on average. This inferred the nitrification in the setup. This was also observed in tube-settler. Tube-settler, compared to SBR, was very low in removal efficiency, with 20% and 17% for COD and BOD. The phosphorous removal was concerned; both SBR and tube-settler had an average reduction of 85%. Based on its result, the study concluded that SBR could successfully treat hospital wastewater. Tube-settler was not suitable for hospital wastewater treatment. Future work can be extended to include inducing denitrification in the SBR setup. This may be achieved by introducing anaerobic and aerobic units in SBR.

The tube-settler was in coherence with the existing wastewater treatment plant installed at a hospital. The operational parameters were optimised using Design expert software, and a four-factor and five-level central composite design were involved using RSM. The percentage removal of COD, nitrate, and phosphate was selected to be observed during this study. The different parameter set during the study was initial COD concentration, mixed liquor suspended solids (MLSS), cycle time, and initial pH value of the initial influent values selected for process parameters for optimisation. Kinetic studies at the optimum conditions suggested that the Grau 2nd order Model and Modified Stover-Kincannon model fitted the data well for both COD. SBR removed BOD₅ and COD from hospital wastewater successfully. The effect of pharmaceutical and other hospital-specific compounds needs to be investigated in future research studies.

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Data availability Not applicable.

Declarations

Ethics approval Not applicable.

Competing interests The authors declare no competing interests.

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