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Optimization of hydraulic retention time (HRT) employing statistical tools of a lab-scale sequencing batch rector (SBR) treating real wastewater of a University campus

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Key words: Activated sludge, Hydraulic retention time, Reclamation, Sequencing batch reactor (SBR), Wastewater.

Abstract

Two lab-scale sequencing batch reactors (SBR) with combined capacity of 45 L/day, each having holding volume of 6 L were installed and operated at Institute of Environmental Sciences and Engineering (IESE) lab. The SBR systems were automated for variable hydraulic retention time (HRT) to treat real university wastewater (average COD = 220 mg/L). The HRT optimized based upon activated sludge growth pattern, and COD & BOD removal rates from unsteady to steady state condition. The optimized results will be utilized for under construction bio-tanks at the full scale membrane bioreactor (MBR) plant for reclamation and reuse of university wastewater. Each treatment cycle was operated with 2 and 3hr HRT (aeration time), followed by 30 minutes settling and 15 minutes decant time. The sludge withdrawal was based upon solids retention time (SRT) of 15 days and approximately 4 g/L mix liquor suspended solids (MLSS). Nutrient removal, COD, BOD, Total suspended solids (TSS), Total dissolved solids (TDS), temperature & pH, extracellular polymeric substances (EPS), microbial counts and Total Organic Carbon (TOC) for influent & effluent and sludge volume index (SVI), EPS, capillary suction time and MLSS/MLVSS for sludge were analyzed through standard operating procedures.

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Introduction

Water being a vital component for the survival of human beings and determines the development of societies. The availability of freshwater resources and its distribution varies around the globe (World Bank, 2005). The water usage in sanitation, drinking, manufacturing, industries, washing and agriculture is polluting water resources to a great extent. It has been estimated that to meet the rising demand for horticulture, many cities will face issues to access fresh water within the next 15 to 25 years (Hastuti *et al.,* 2011).Due to the increasing demand of water usage, Pakistan is shifting from water stressed country to a water scarce one. In Pakistan, 23% population lack access to fresh and safe water for drinking and 30% population lack access to sanitation (World Bank Report, 2006).

The prevailing situation in country demands the conservation of water resources and requires the treatment of wastewater so that it can be utilized for irrigation, landscaping and ground water recharge purposes. Conventional wastewater treatment processes are not effective in meeting the effluent discharge standards especially in the removal of pathogens. The impacts of discharging untreated wastewater into the environment have significant health and ecological impacts specially on biodiversity (Asadi and Ziantizadeh, 2011, Mamert *et al.,* 2016). The physico-chemical Wastewater treatment are costly and raises issues of sludge disposal; which urges us for cost effective treatment processes such as biological treatment systems for removing pollutants and also does not leave chemical sludge. (Kapdan and Oztekin, 2006, Matsumoto *et al.,* 2012, Lim and Vadivelu, 2014).Biological treatment has capacity to remove the concentration of organic and inorganic compounds and also to transform nutrients (Nawaz and Jamal Khan, 2013). Sequencing Batch Reactors (SBR) is sequential suspended growth (activated sludge) process, where all steps are carried out in a single tank (Lamine *et al.,* 2007, Xu *et al.,* 2014). SBRs are used all over the world to treat both industrial and municipal wastewaters, predominantly in sectors having low and changing flow patterns (Chan *et al.,* 2009, Calderón *et al.,* 2013, Chen *et al.,* 2015).

This demands more research in this field to make treatment processes efficient and economical. Keeping above in consideration, this research aims to obtain the following objectives (a) Installation of automated lab-scale SBR setup (b) Temporal characterization of NUST wastewater (c) Optimization of HRT using statistical analysis (d) Comparison of SBR performance with synthetic and real wastewater. There are few studies available on lab scale set-up before moving to full scale plant. In order to save money, time and effort, this lab scale SBR was used to comprehensively analyzed and observe the treatment process before moving to pilot scale or full scale SBR at NUST campus.

Materials and methodology

Experimental setup

Two bench scale sequencing batch reactors were setup at IESE wastewater laboratory. The volume of each reactor was six liters. Four liters of wastewater was treated in each cycle and one third of the reactor volume that is two liters was having sludge. The mixed liquor suspended solids (MLSS) was kept in range of 3-5 mg/l and sludge retention time (SRT) was 15 days and daily sludge discharge rate was 400ml. Aerators having same capacity were provided to each reactor. One Feed tank was installed on upper head to provide same quality influent for both reactors under gravity flow. Each reactor was provided with three timers to control inlet, aeration and effluent in a sequence. These reactors were categorized based on the hydraulic retention time (HRT). The filling and decant time was set at30 minutes and settling for 1 hour.

The study was conducted in two phases. In first phase, the reactors were operated on synthetic wastewater on the hydraulic retention time (HRT) of 1, 2, 3 and 4 hours. For all the HRTs, sludge and wastewater parameters were analyzed and statistical analysis was conducted. HRT of 2 hours were statistically optimized and HRT of 2 and 3 hrs were shifted to real wastewater for further analysis.

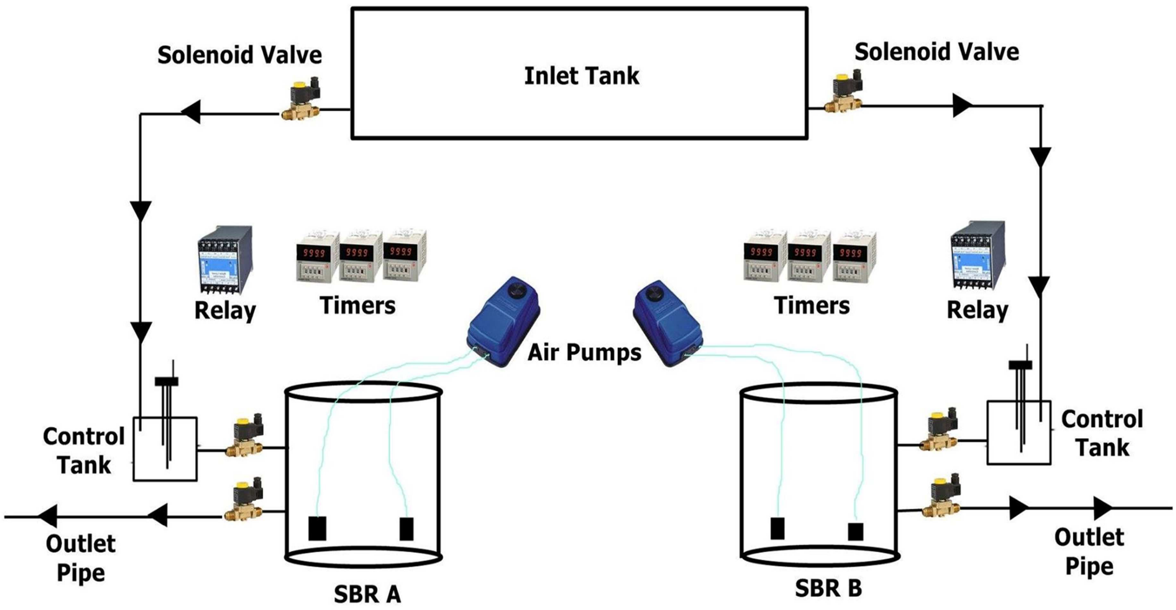

Fig. 1. Schematic Diagram of Lab Scale Sequencing Batch Reactor.

Phase I

In first phase, synthetic wastewater was used for the acclimatization of sludge, analysis of parameters on different HRTs and statistical analysis. Synthetic waste water with a medium strength having C: N: P as 100:10:2 was used as substrate.

Analytical Methods

Chemical Oxygen Demand (COD), Orthophosphates-p and Total Suspended Solids (TSS) were analyzed wastewater parameters while sludge parameters include Sludge Volume Index (SVI), MLSS and CST. All these parameters were analyzed as per Standard Methods for the Examination of Water & Wastewater, 22st Edition 2012 (APHA, 2012). COD was measured using COD reactor, Nutrients and Phosphates using Hach meter. SVI was done to monitor the settling characteristics of sludge using Imhoff cones and MLSS using Whatzman filter paper 47mmØ&filter assembly.

Phase II

Real Wastewater Collection

Real wastewater of NUST was collected from NUST main drain. The sample was collected using global water sampler mostly in the morning around 08:00-09:00 am and 02:00-03:00 pm when there was a high load of COD and nutrients in wastewater.

Analytical Methods

For real wastewater, on optimized HRTs of 2hr and 3hr, the wastewater parameters comprised Chemical Oxygen Demand (COD), Nitrates, Nitrites, Ammonium-N (NH_4-N), Phosphates (Total & Ortho) and Total Suspended Solids (TSS) while sludge parameters analyzed Mixed Liquor Suspended Solids (MLSS), Sludge Volume Index (SVI), Extra Polymeric Substances (EPS), Capillary Suction Time (CST) using TYPE 304B CAPILLARY SUCTION TIMER and Particle Size Analysis (PSA) was measeured using HORIBA Laser Scattering Particle Size Distributon Analyzer.

EPS determines the extracellular polymeric substances in form of soluble, loosely and tightly bound present in the sludge. All these are further catagorized in polysaccharides and proteins. The more the tightly bound substances present, the more become its particle size. Because of this, its dewatering capacity is enhanced and its capillary suction time (CST) reduces. Statistical analysis was done for all analyzed parameters on both 2hr and 3hr HRTs for the optimization.

Statistical Analysis

In statistical analysis, two tools were used, the first is the analysis of variance (ANOVA) and the second one is two tail t-test. ANOVA determines the statistically significant distinction among more than two scenarios while Post hoc Test (Two Tail t-Test) shows the statistically significant distinction between a pair of scenarios. Both of these tests were based on a hypothetis which is called null hypothesis. Our null hypothesis for both tools was as follows:

For ANOVA, Ho : $\mu 1=\mu 2=\mu 3....\mu i$; Ha : At least one of mean reduction is distinct

μi : % mean reduction of COD of i^{th} hour sample

For Two Tail t-Test, Ho : $\mu 1=\mu 2$; Ha : $\mu 1 \neq \mu 2$. To approve this hypothesis,

P-value= Probability usually a confidence level of 2%, 5% and 10% is used whereas we accepted confidence of 5% which is also called probability of null which determines whether there is a fair chance to accept the hypothesis or not. So if p value is less than 5%; null hypothesis can be rejected because there is a less probability that our hypothesis is accepted which was that for both the scenarios, the percentage mean reduction was same. So we can reject the null and conclude that both percentage reductions are statistically significantly different on the average. In case if p value is greater or equal than 5%; null hypothesis cannot be rejected which means that both the reactors is statistically significantly same.

Results and discussion

Phase I - Synthetic Wastewater

Effect of Hydraulic Retention Time (HRT) on MLSS and SVI

MLSS concentration remained between 3-6 g/L for both 1 hr and 2 hr HRTs. On average, MLSS of 2hr HRT was 4.53g/L, slightly higher than the MLSS of 1hr HRT which was 4.48g/L (Fig.2-a). The reason is 1hr HRT was not enough for microbes to utilize the food properly that's why its SVI exceeded 150 mL/g which showed its poor settling characteristics. Problem of sludge bulking were also experienced for 1hr HRT. While for 2hr HRT, sludge was dense and showed good settling characteristics as its average SVI was 83.90 mL/g shown in fig.2-b.

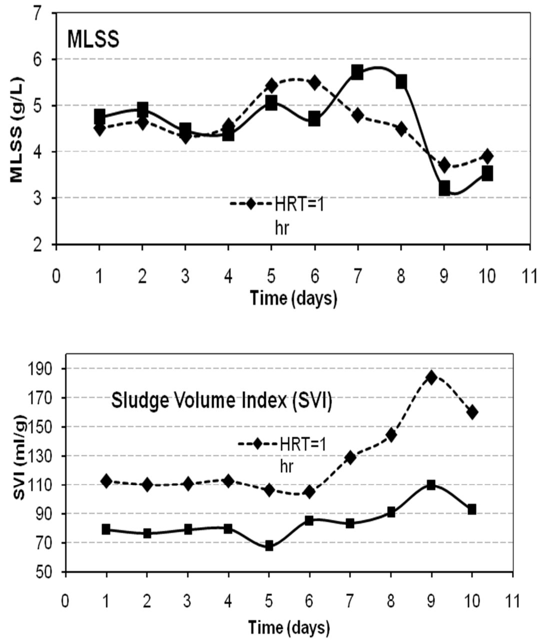

Fig. 2. (a) MLSS concentration of 1hr and 2hr HRT (b) MLSS concentration of 3hr and 4hr HRT.

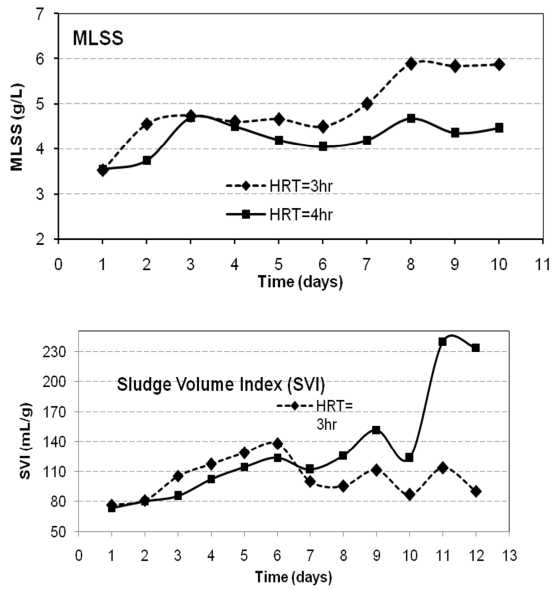

Fig. 3. (a) MLSS concentration of 3hr and 4hr HRT (b) MLSS concentration of 3hr and 4hr HRT.

Referring to fig.3, comparison was made between 3hr and 4 hr HRT. The MLSS concentration of 3hr HRT was higher than 4hr HRT as the average MLSS concentration for 3hr HRT was 4.94g/L and for 4hr HRT, it was 3.95g/L. The sludge of 3hr HRT had better settling than 4hr HRT as its average SVI value was 103.66mL/g. The average SVI for 4hr HRT was 130.47mL/g.

COD Removal Efficiency for different HRTs

For 1hr HRT, due to its poor settling characteristics and sludge bulking issues, its COD removal was insufficient so we did not mention its data here. For all others, COD removal efficiency kept on increasing as the sludge got acclimatized. For 2hr HRT, average COD removal was recorded as 84.89g/L, for 3hr HRT, it was 85.63g/L and was 87.11g/L for 4hr HRT. The COD concentrations at influent and effluent along with their efficiencies for 2hr, 3hr and 4hr HRTs are shown in fig.4-a, b & c. From there graphs, it can be observed that there is a slight difference between the COD removal efficiency of 3hr and 4hr HRT. So it is suitable to work at 3hr to be cost and energy efficient as 1 extra hour results in only 2% increase in COD removal efficiency.

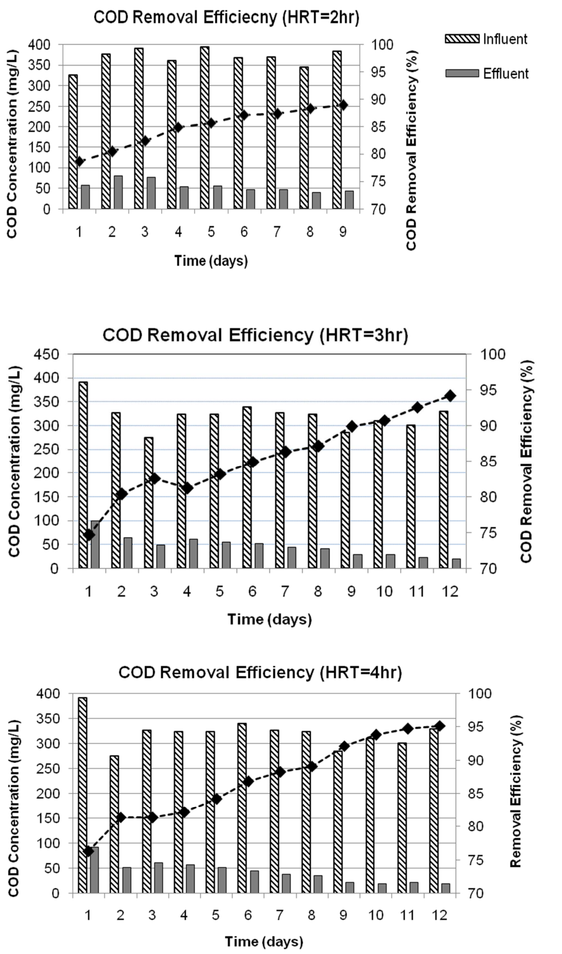

Fig. 4. (a) COD removal efficiency for 2hr HRT (b) COD removal efficiency for 3hr HRT (c) COD removal efficiency for 4hr HRT.

Orthophosphates Removal Efficiency on Different HRTs

Orthophosphate removal efficiency was almost same for 2hr, 3hr and 4hr HRTs as shown in fig.5-a, b & c.

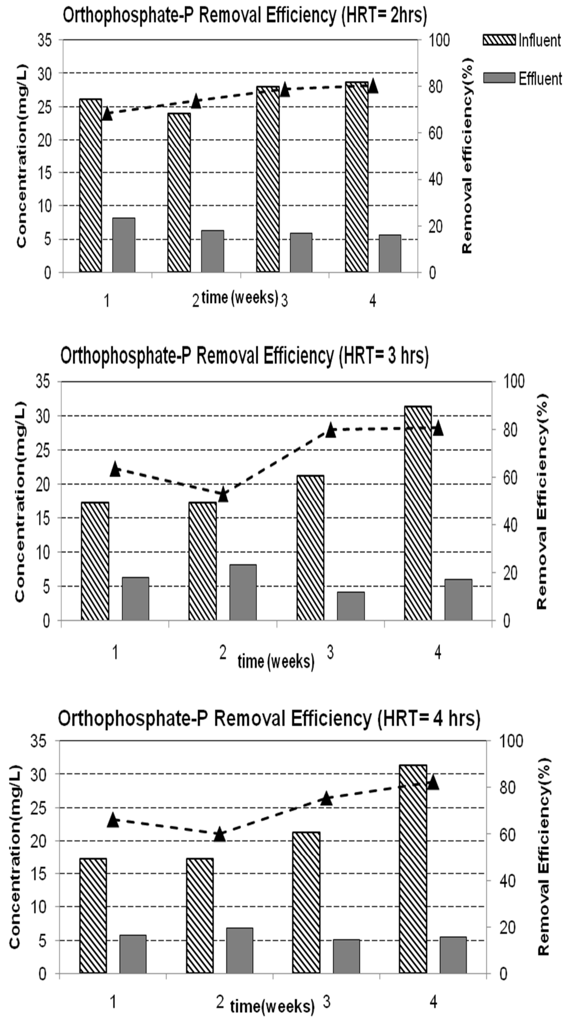

Fig. 5. (a) Orthophosphate-P removal efficiency for 2hr HRT (b) Orthophosphate-P removal efficiency for 3 hr HRT (c) Orthophosphate-P removal efficiency for 4 hr HRT.

It can be observed from above graphs that on average, phosphate removal efficiency of 2hr HRT was recorded as 75.56% which was better than 69.41% and 71.19% for 3hr and 4hr respectively. This is due to its high MLSS concentration. There is more phosphate accumulating organisms (PAOs) present in 2hr HRT due to more presence of mixed liquor suspended solids.

Phase II - Real Wastewater

The Effect of HRT on MLSS and SVI

Fig.6-a illustrates the MLSS variations in both SBR reactors (i.e. HRT=2hr, HRT=3hr).As we can observe from graph that both reactors have a lot of variation in MLSS concentration due to the diurnal COD concentration in influent. Also we can observe that MLSS concentration of HRT 2 is greater than HRT 3.The average concentration of MLSS of HRT 2hr and HRT 3hr is 3.4 g/L and 2.8 g/L respectively. The reason behind increased MLSS of HRT 2hr is that the reactor with HRT 2 is completing more cycles than HRT 3 per day, and hence getting more food in term of influent COD. As MLSS and SVI has indirect relation, so for 2hr HRT, SVI is 46.32 mL/g on average and the sludge is dense and has good settling characteristics. While for 3hr HRT, the SVI is 60.56 on average which is greater than of 2hr as its MLSS is less but the sludge is in a good settling range as shown in fig. 6b.

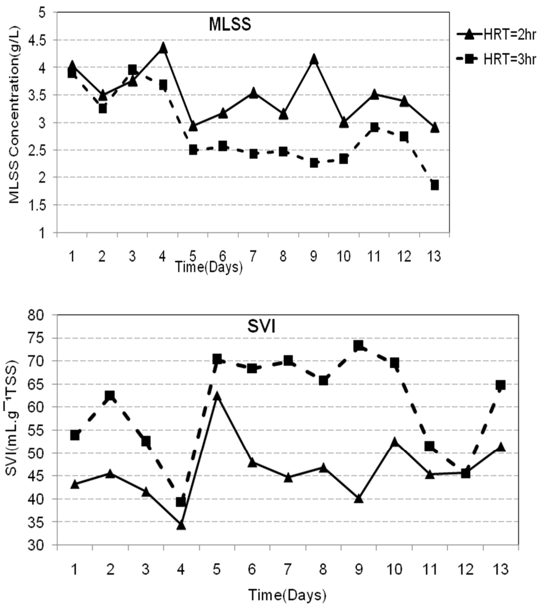

Fig. 6. (a) MLSS concentration of 2hr and 3hr HRT (b) SVI concentration of 3hr and 4hr HRT.

The Effect of HRT on COD Removal

The COD removal is the most important parameter for assessing the performance of SBR. Fig. 7 shows the COD removal patterns of both SBR reactors at two different HRTs (i.e. at HRT=2hr and HRT=3hr) for real wastewater.

Because of the real wastewater, there was a lot of fluctuation in inlet filtered COD concentrations ranging from 80-230 mg/L.

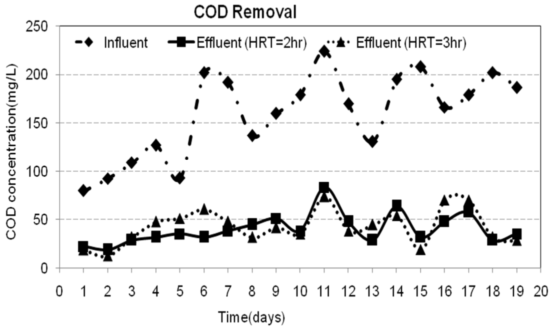

Fig. 7. COD concentration at influent and effluents.

Fig. 8a & b are the combination graphs which show the influent, effluent concentration along with removal efficiencies for both 2hr and 3hr HRT respectively. As shown in both graphs, the fluctuation in COD at influent was observed which resulted in the variations in COD removal efficiency as MLSS did not increase with a same rate as in the synthetic wastewater. On average, 2hr HRT showed a high COD removal efficiency than 3hr because of its higher MLSS. The more the MLSS, the more the microbes present to remove COD and higher becomes the COD removal efficiency.

Fig. 8c shows the per hour comparison between COD removal efficiency of 2hr with 3hr HRT. It can be easily observed from graph that removal efficiencies of 2hr HRT in both first and second hour is greater than 3hr HRT due to the increased MLSS in 2hr HRT reactor as discussed earlier. Also the removal efficiency of 2hr HRT increased more rapidly (53%-74%) than 3hr HRT (45%-62%).

The Effect of HRT on Ammonia Removal

Fig. 9a & b are the combination graphs of ammonia nitrogen removal of reactors with HRT 2hr and HRT 3hr respectively. The ammonia removal efficiency kept on decreasing for both reactors. This might be due to the hindrance in the conversion of ammonia into nitrites as we converted our setup from synthetic to real wastewater. The reduction was almost same for both reactors.

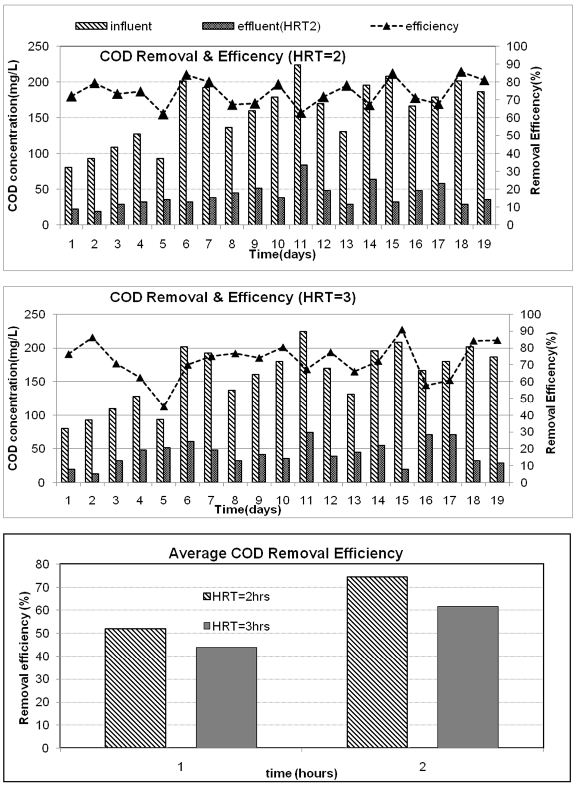

Fig. 8. (a) COD removal efficiency for 2hr HRT. (b) COD removal efficiency for 3hr HRT (c) On average COD removal efficiency.

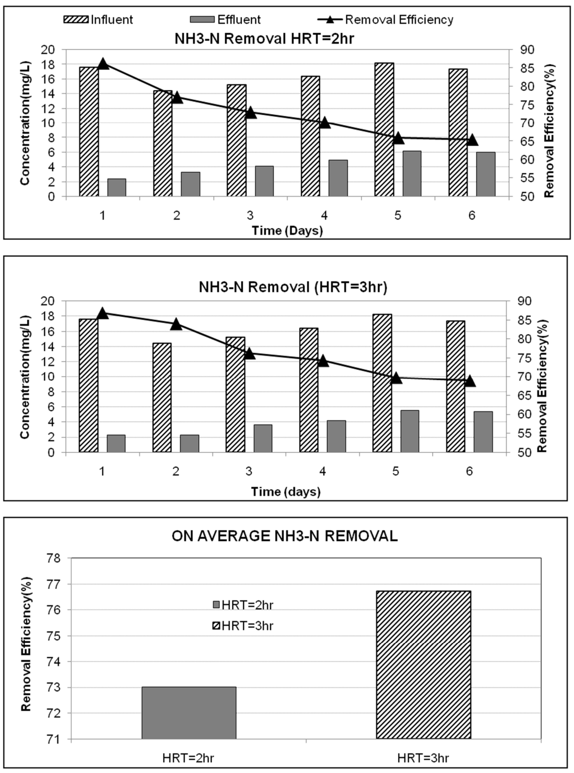

Fig. 9. (a) Ammonia removal for 2hr HRT (b) Ammonia removal for 3hr HRT (c) On average Ammonia removal for 2hr and 3hr HRT.

Fig. 9c shows the average removal efficiencies of both HRT's in same graph. From fig. 9-c, we can observe that the average ammonia nitrogen removal of HRT=3hr is greater than HRT=2hr because the nitrifying microbes present with in reactor with HRT=3hr is getting an extra hour for nitrification process as compare to reactor with HRT=2hr, as ammonia nitrogen is converted into nitrites through the processes of nitrification.

The Effect of HRT on Nitrite Removal

Fig. 10a & b shows the nitrites removal graphs of both SBR reactors with HRT 2hr and HRT 3hr respectively. On average the nitrite removal for 2hr HRT was 85.02% which increased to 88.91% when it got as extra hour in 3hr HRT due to complete nitrification process.

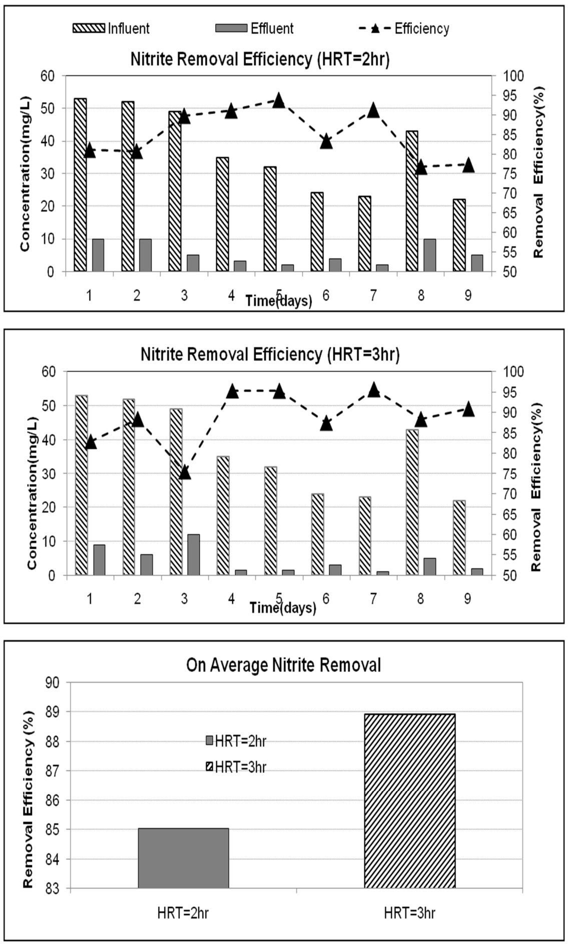

Fig. 10. (a) Nitrite removal efficiency for 2hr HRT (b) Nitrite removal efficiency for 3hr HRT (c) On average Nitrite removal.

Fig. 10c represents the on average nitrite removal of both SBR reactors with HRT 2hr and HRT 3hr respectively. We can observe that average nitrite removal in SBR reactor with HRT 3hr is greater than reactor with HRT 2hr.The reason is that the reactor with HRT 3hr is getting an extra hour for complete nitrification that is converting nitrite into nitrates as compare to reactor with HRT 2hr.

The Effect of HRT on Nitrate

Fig. 11a & b shows the Nitrates increase in effluents as compare to the inlet, of both reactors with HRT 2hr and HRT 3hr respectively. An increase in the nitrate concentration was observed at the effluent for both HRTs.

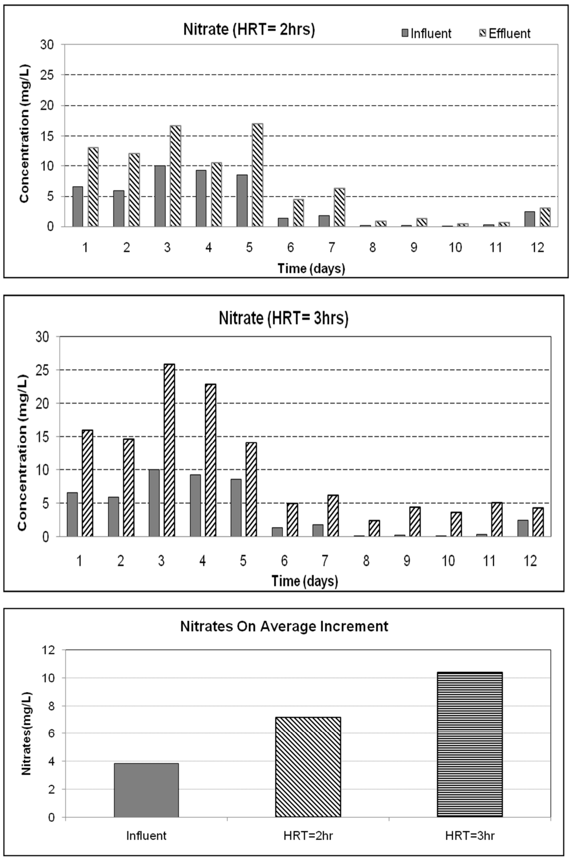

Fig. 11. (a) Nitrate concentration at influent and effluent for 2hr HRT (b) Nitrate concentrations at influent and effluent for 3hr HRT (c) On average Nitrate increment for 2hr and 3hr HRT.

The reason behind the increase of nitrates at effluents as compare to inlet concentration is that, nitrification (oxic) was the only step being performed in SBR treatment in our case, which converts ammonia nitrogen into nitrite and then nitrates.

If we were performing the de-nitrification step in our process then the nitrate concentration at effluent would be less than inlet concentration, because de-nitrification (anoxic) process converts the nitrates into the nitrogen gas.

Fig. 11c shows on average increment in nitrate concentration for both HRTs. On average, the inlet nitrate concentration was 3.86mg/L which increased to 7.17mg/L in 2hr HRT and 10.39mg/L in 3hr HRT.

The Effect of HRT on Ortho and Total phosphates

Fig. 12a & b shows the removal efficiencies of orthophosphates along with inlet and outlet concentrations of both SBR reactors with HRT 2hr and HRT 3hr. We can observe from fig. 12-a & b that average removal efficiency of orthophosphates is greater in SBR reactor with 2hr HRT, than 3hr HRT reactor. This is because of the greater concentration of MLSS in SBR reactor with HRT 2hr. Phosphorus is up taken by microbes as energy source, and as the microbial concentration in reactor with HRT 2hr is greater, that's why more phosphorus accumulating microorganisms (PAO's) are present there which uptake the phosphates.

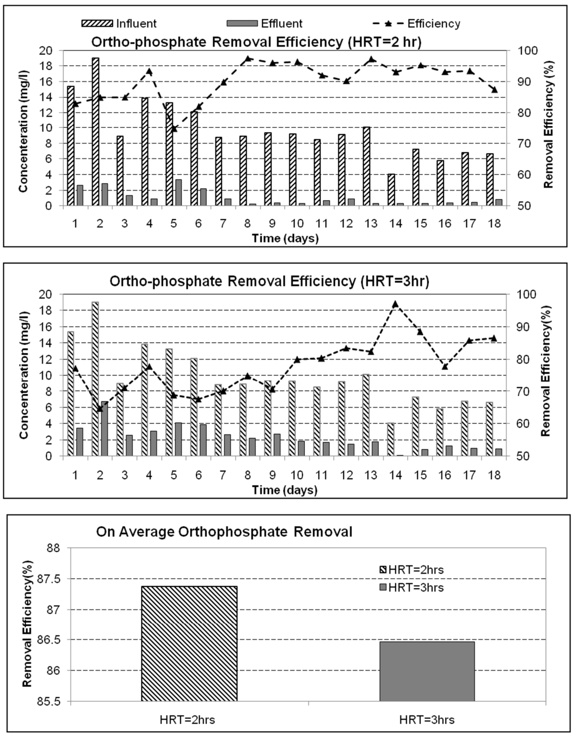

Fig. 12. (a) Orthophosphate removal efficiency for 2hr HRT (b) Orthophosphate removal efficiency for 3hr HRT (c) On average Orthophosphate removal for 2hr and 3hr HRT.

Fig. 12c shows the on average orthophosphate removal for both 2hr and 3hr HRTs. For 2hr, its removal efficiency was 87.37% on average and for 3hr, it was 86.47%.

Similarly, fig. 13a & b shows the removal efficiencies of total phosphates along with inlet and outlet concentrations of SBR reactors with HRT 2hr and HRT 3hr. A similar pattern can be observed for total phosphates that the 2hr HRT performed better in total phosphate removal due to its high MLSS.

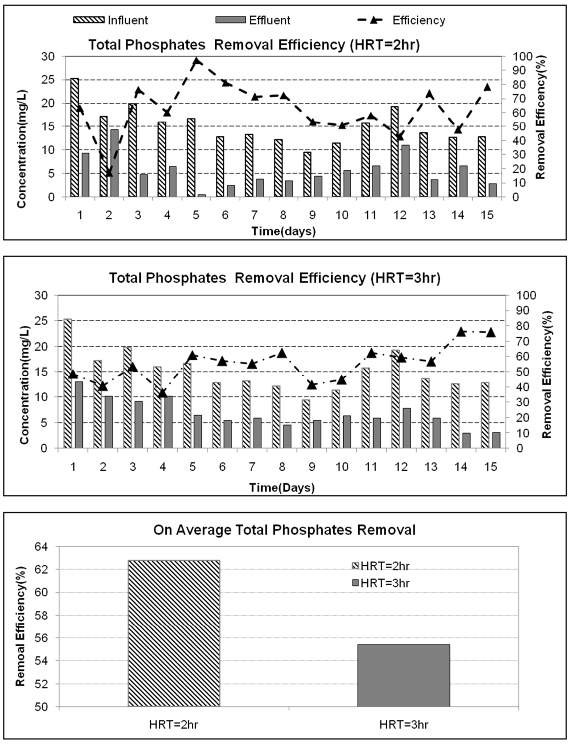

Fig. 13. (a) Total phosphate removal efficiency for 2hr HRT (b) Total phosphate removal efficiency for 3hr HRT (c) On average Total phosphate removal for 2hr and 3hr HRT.

Fig. 13c shows the on average total phosphate removal for both 2hr and 3hr HRTs. For 2hr, its removal efficiency was 62.80% on average and for 3hr, it was 55.42%.

Sludge Parameters

Sludge parameters analyzed were particle size analysis, extracellular polymeric substances and capillary suction time along with their MLSS and SVI which were mentioned above.

Particle size analysis was done for both HRTs. Mean particle size was 7.57 µm for 2hr HRT and mean particle size for 3hr HRT, it was 6.08 µm (Fig. 14-a & b).

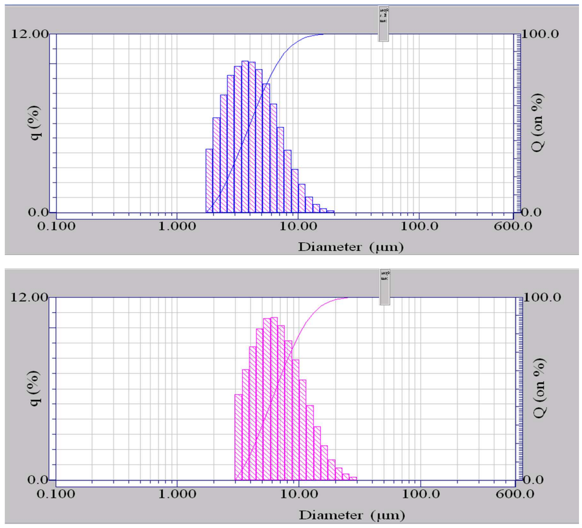

Fig. 14. (a) PSA result of 2hr HRT (b) PSA result of 3hr HRT.

The results for EPS are demonstrated in table 1. For 2hr HRT, due to its high MLSS there are more tightly bound EPS. EPS in 2hr HRT was 115.23 mg/L of polysaccharides as tightly bound substances which was way ahead of 26.61mg/L of 3hr HRT. Also for 2hr HRT, there are less soluble EPS present as compared to 3hr HRT.

Table 1. EPS results for both HRTs.

Extracellular Polymeric Substances (EPS)			
		HRT = 2hrs	HRT = 3 hrs
EPS soluble (mg/L)	PS (polyschrides)	12.041	26.831
	PN (protines)	3.6895	6.7245
EPS loosly bound(mg/L)	PS	73.096	13.6885
	PN	86.59	11.0525
EPS tightly bound(mg/L)	PS	115.298	26.6065
	PN	30.817	30.817

Table 2. Results of sludge parameters.

Sludge Parameters	HRT = 2hrs	HRT = 3 hrs
MLSS(g/mL)	3.44	2.80
SVI(mL.g^{-1}TSS)	46.85	59.62
CST(seconds)	10.03	11.33
PSA(micrometer)	7.57	6.08

Table 2 illustrates the results of further sludge parameters which include particle size analysis and capillary suction time. From the table, it can be observed that 2hr HRT has higher tightly bound EPS than 3hr HRT which results in larger floc size of 7.57um. Larger the floc size, more is the hydraulic conductivity and higher is its dewater ability and lesser will be the capillary suction time for sludge with HRT 2 hr, which was 10.03 seconds compared to 11.33 seconds for 3hr HRT shown in table 2. Hence sludge with lower CST will settle earlier.

Optimization of HRT by Statistical Analysis

In order to optimize the HRT statistically among 2hr or 3hr, statistical analysis applied like 2 Tail test and ANOVA test to each parameter on the basis of percentage removal efficiencies. 2 tail t-test is used for comparison between two scenarios and ANOVA test is used for comparison between multiple scenarios. Before going to statistical analysis it is necessary to understand some statistical descriptions.

Null Hypothesis: Before applying statistical analysis between two scenarios e.g. Reactor with HRT 2 and HRT 3 it is our assumption or hypothesis that percentage removal Efficiency of both reactors is same at a bench mark of 5%.

So regarding the application of 2 tail test on HRT 2hr and HRT 3hr reactor for any single parameter, there are two options that arises

1) If p value < 5% then we can reject the null hypothesis, means both reactors are statistically distinct so, we must go for next hour of aeration of further removal.

2) If p value >5% then we can't reject the null hypothesis, means both reactors are statistically same and there is no statistical significant difference so, we must not go for next hour of aeration.

Reactors Validation through Statistical Analysis

For the statistical validation of both SBR Reactors, that both reactors are operating at same conditions we applied the 2 tail test upon 1st hour percentage COD removal efficiency of both SBR reactors with HRT 2hr and HRT 3hr respectively. 2-1 and 3-1 indicates 1st hour of both HRT 2hr and HRT 3hr respectively.

Table 3. Validation of SBR reactors.

Two Samples T-test	2—1 (Reactor-B)	3—1 (Reactor-A)
Mean	51.795	43.815
Variance	333.120	331.038
df	36	36
t Stat	1.349	
P(T<=t) two-tail	0.186	
t Critical two-tail	2.028	

Table 3 shows that, p value >5% so we can't reject the null hypothesis,hence the efficiency of both the reactors is statistically significantly same which means both reactors were operating at same conditions.

Statistical Analysis on Analyzed Parameters

Firstly, we applied ANOVA to determine the distinction between all 3 hours of reactor with 3hr HRT. As p value came out to be <5% so we can reject the null which means there is a statistically significant difference in COD removal between each hour of 3hr HRT reactor as shown in table 4.

Table 4. ANOVA results.

Analysis of Variance (ANOVA)			
Summary			
Groups	A-1	A-2	A-3
Where A-1, A-2 and A-3 are 1 hr HRT, 2hr HRT and 3 hr HRTs.			
Average	43.81	61.81	72.44
Variance	331.04	148.05	124.31
ANOVA			
f-stat		19.77	
P-Value		3.61×10^{-07}	
F critical		3.17	

Secondly, Post-Hoc (two tail t-test) was used to find out statistically significant distinction between the pair of %age reductions. While comparing 1st and 2nd hours of 3hr HRT, p value came out to be <5% which means we can reject the null hypothesis and should move to 2nd hour of aeration as there is a statistically significant difference in COD removal.

In comparison of 2nd and 3rd hour, p value again came out to be <5%, so we should move for the 3rd hour for further COD removal as shown in table 5and6. So for COD removal, HRT of 3hr came out to be statistically optimized.

Table 5. Two tail t-test results for 1st and 2nd hour.

t-Test: Two-Sample assuming equal variances	HRT = 3 hrs	
	3--1	*3--2*
Mean	43.815	61.802
Variance	331.038	148.056
df	36	
t Stat	-3.582	
P(T<=t) two-tail	0.001	
t Critical two-tail	2.0281	

Table 6. Two tail t-test results for 2nd and 3rd hour.

t-Test: Two-Sample assuming equal variances	HRT = 3 hrs	
	3--2	3--3
Mean	61.802	72.437
Variance	148.056	124.312
df	36	
t Stat	-2.809	
P(T<=t) two-tail	0.008	
t Critical two-tail	2.028	

Similarly, statistical analysis was done for other parameters and the results are shown in table 7 which shows the p-value for other parameters. On the basis of P-value we can conclude that the optimal HRT is 3 hrs for COD, Ammonium-N and nitrite removal. For the removal of Ortho Phosphate and TP optimal HRT is 2 hrs.

Table 7. Results of statistical analysis.

Parameter	P (T <=t) two-tail	Hypothesis on the average percentage reduction is same for 2 & 3 hours	Conclusions
COD	0.008	P <5%, the null hypothesis can be rejected.	OHRT is 3 hrs
Ammonium-N	0.04	P <5%, the null hypothesis can be rejected.	OHRT is 3 hrs
Nitrate-N	0.02	P <5%, the null hypothesis can be rejected.	OHRT is 3 hrs
Orthophosphate-P	0.10	P <5%, the null hypothesis can be rejected.	OHRT is 2 hrs
Total Phosphate	0.33	P <5%, the null hypothesis can be rejected.	OHRT is 2 hrs

Conclusions

The conclusions of this research are (a) Both reactors of lab scale SBR setup are statistically calibrated, (b) Optimal Hydraulic Retention Time (OHRT) for synthetic wastewater is 2hr for Orthophosphate-P & Total Phosphate whereas 3hr for COD, Ammonium-N and Nitrate-N, (c) Optimal Hydraulic Retention Time for real wastewater for most of the analyzed parameter is 3hr. This research can be further enhanced in future by (a) adding a mixer to improve de-nitrification in anoxic conditions and (b) adding coagulant to reduce settling time in case SVI is greater than 100ml/MLSS.

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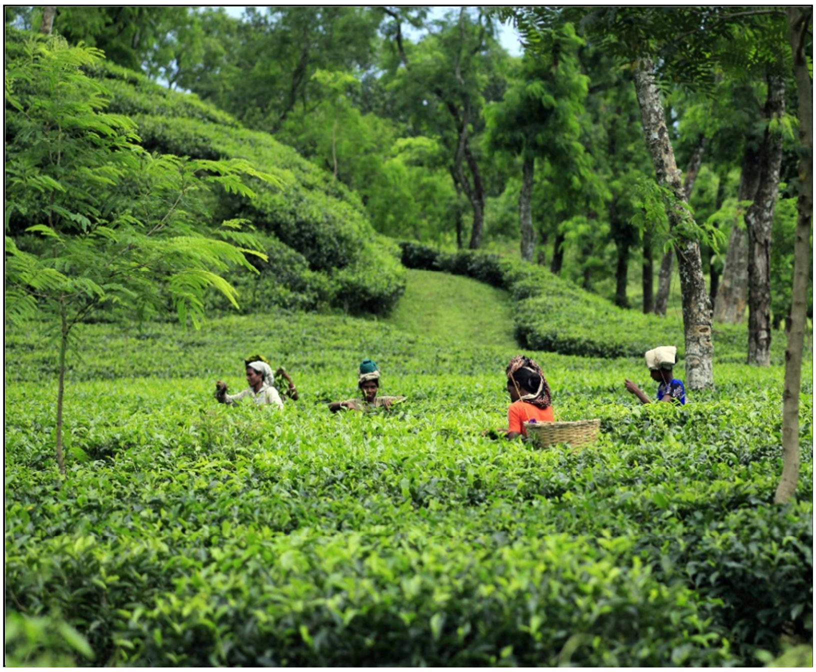

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