A Study on Sequential Batch Biofilm Reactor

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Abstract: With the introduction of the stringent standard by the pollution control board, it is our responsibility to treat the sewage to comply with the standards of receiving streams. We are aware of the suspended growth process like Activated Sludge Process (ASP) and Sequential Batch Reactor (SBR) and attached growth process like Moving Bed Biofilm Reactor (MBBR). Nowadays a new trend is developed to adopt the combination of suspended and attached growth process for wastewater treatment. In SBR, four processes fill, aeration, settling and decanting take place with certain retention time where microorganisms are present in suspended form. In MBBR, microorganism's growth takes place on the PVC media in aeration tank and secondary settling takes place in another tank with certain retention time. So the present study will show the feasibility of a Sequential Bed Biofilm Reactor (SBBR) with a combined suspended and attached growth system for the treatment of domestic sewage. Compared with an SBR and MBBR, SBBR has many advantages, such as more biomass and higher removal efficiency, less sludge and sludge conglomeration, greater volumetric loads and increased process stability toward shock loadings. The main advantage of SBBR compared to SBR and MBBR is higher nutrient removal efficiency in the context of nitrogen and phosphorus removal. The study will show COD, TP, TKN and TSS parameters with different detention time and organic loading. Domestic sewage flowing through the SBBR will receive the extensive treatment with least consumption of energy.

Keywords – *Sequential Batch Reactor (SBR), Moving Bed Biofilm Reactor (MBBR), Activated Sludge Process (ASP)*

1. Introduction :

Wastewater treatment is becoming crucial day by day due to increasing the wastewater generation in the city due population explosion. Growth of urbanization in India is at rapid rate. As per the WATER (PREVENTION AND CONTROL OF POLLUTION) ACT, 1974 "Sewage Effluent" means effluent from any sewerage system or sewage disposal works and includes sullage from open drains.In India, most of the cities have conventional sewage treatment plant (ASP based) and ASP based treatment plant BOD removal efficiency is 60-70%, COD removal efficiency is 55-65 % and Ammoniacal Nitrogen removal is 10-20 %. Whereas modern technologies like SBR and MBBR can overcome these challenges. We are striving for the solutions where domestic sewage treatment can become more advanced.

2. Literature Survey:

Koul, A., John, S.(2015), The average removal percentages of BOD were 88.58% and 79.32% for SBR and MBBR respectively. The average removal percentages were 71.75% and 74.36% for SBR and MBBR respectively. In the present study, the BOD removal efficiency varied in the order SBR > MBBR. The COD removal was in the order MBBR > SBR. The TSS removal efficiency followed the order MBBR > SBR. The nitrates removal efficiency was in the order MBBR > SBR [7]. If COD removal is achieved more in MBBR and BOD removal is achieved more in SBR then why we should not go for the combinations of the two systems? Rajput, D. C., Khambete, A. K.(2015), The laborator scale SBBR with the cycle time 8 hour, which was the COD and suspended solids removal reported were 95% and 93%, respectively. Average COD concentration is 28.53±20 for SBBR. The average BOD removal rate was 87.22%. Average effluents of BOD concentration were 12.33±6.73 for SBBR. The average Ammonical nitrogen removal rate was 67.8%. Average effluents of Ammonical nitrogen concentration were 1.27±0.41 [12]. Hanh Van N., Phong Tan N.(2013), A sequencing batch moving bed biofilm reactor (SBMBBR) system on 5 steps using K3 media with surface area is 175 m2 /m3 increases effectiveness compared to traditional sequencing batch reactor (SBR) system on fishery wastewater treatment. The COD, TKN and TP removal efficiency under the last organic loading of 2000 ± 40.4 g COD/m3 .d were 94.6 ± 0.2%, 53.4 ± 3.9%, 50.0 ± 3.2% and 89.8 ± 2.5 mg/l, 92.7 ± 0.9 mg/l, 12.5 ± 0.5 mg/l. The TKN removal of SBMBBR was higher than SBR because of the following reasons: the total bio-sludge mass was increased the quantity in the attached bio-sludge in the surface of media, this attached microbial growth provided increased rates of waste degradation and removal, and thought to be particularly well suited for increasing rates of ammonia conversion to nitrate (nitrification) [5]. 2 Sirianuntapiboon, S.,Yommee, S.(2006), The moving bio-film (MB) might be applied in the conventional aerobic-SBR to increase the amount and quality of bio-sludge of the system resulting in improvement of the effluent quality and system efficiency. In this study, a new type of MB was applied into the conventional aerobic-SBR. The efficiency and bio-sludge quality of the system was determined under various organic loading and HRT operations to compare with conventional-aerobic-SBR. BOD5 and TKN removal efficiencies of the MB-aerobic-SBR were about 10–20% higher than the conventional-aerobic SBR, respectively [13].

Gulhane, M. L., Kotanjale, A. J.(2014), Hybrid Moving Bed Biofilm Reactor working in combination with Attached and Suspended Growth Reactor will provide better results as compared to normal Moving Bed Biofilm Reactor. Higher efficiency in terms of BOD and COD removal is expected when the domestic wastewater will be treated in combination of treatments [4].

3. Objective :

The overall objectives of this research are to investigate the potential and to in-turn optimize the design and operation of the SBBR technology for the treatment of carbon, nitrogen, and phosphorus from Domestic wastewater. The research moves beyond design and optimization of the SBBR technology and endeavors to provide new knowledge of this technology at the macro-, meso-, micro-, and molecular-scale. Specifically, this research will (i) study the effects of anaerobic staging on the kinetics of carbon, nitrogen, and phosphorous removal of a single SBBR system; (ii) study the effects of aeration rates on the kinetics of carbon, nitrogen, and phosphorous removal of a single SBBR system; (iii) study the effects of anaerobic staging on the biofilm dry-mass, thickness, morphology, biomass viability, and microbiome of a single SBBR system; (iv) study the effects of aeration rates on biofilm dry mass, thickness, morphology, biomass viability, and microbiome of a single SBBR system; (v) compare two strategies for achieving TAN oxidation in a high loaded SBBR system.(vi) 5 compare the biofilm dry-mass, thickness, dry-density, morphology, viability and microbiome of the two strategies for achieving TAN oxidation in a high loaded SBBR system; (vii) study the kinetics of the carbon, nitrogen, and phosphorous of a two SBBR in series system; and (viii) study the biofilm dry-mass, thickness, dry-density, and morphology of the of the two SBBR in-series system.

The aim of this study is to investigate the potential and evaluate the performance of the SBBR cycling between anaerobic and aerobic stages to treat high-strength Domestic wastewaters. Increasing anaerobic staging times was found to improve the removal rates of carbon beyond previously reported moving bed biofilm reactor (MBBR) results. Increasing the anaerobic stage however decreased the total nitrogen removal, with organic nitrogen undergoing ammonification during the anaerobic stage. Specifically, this study focuses on the effects of anaerobic staging times and enhanced aeration on the removal of carbon, nitrogen, and phosphorus from Domestic wastewaters generation.

4. Material and Process Description

Pilot Scale Reactor

A. The experiments were carried out in lab-scale reactor; the SBBR as illustrated in Fig. 1. Reactor is made up of 2mm thickness Mild Steel(MS) sheet. The design of SBBR is done with the basic principles of the SBR and MBBR. The capacity of reactor is 100 L/day. The reactor was operated as SBBR. SBBR was filled with the biomedia 25% of the working volume [5]. Compressed air was supplied via diffusers at the bottom of the SBBR reactor. Mixing was performed in separate anoxic provided in the system. This SBBR system is working with the pre-anoxic system because its required carbon source to convert nitrate into nitrogen gas for efficient removal of Total Nitrogen from the wastewater. The dissolved oxygen (DO) concentrations were maintained above 3mg/L in the SBBR. Experiments were conducted at room temperature. Minimum DO concentration was maintained 2-3mg/L throughout the pilot scale set up to maintain the biofilm under appropriate conditions [12]. Activated sludge was obtained from a local municipal WWTP as a seeding material to the reactor. Wastewater was fed and discharged by means of the Bernoulli's principle. The procedures of the reactor operation, such as feeding, aerating, settling and decanting, were controlled time to time by manually.

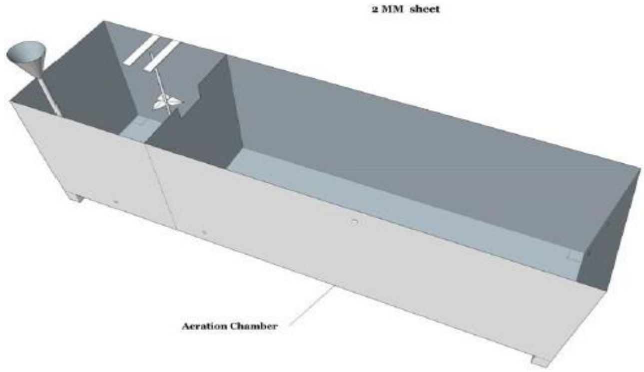


Fig. 1 Pilot Scale Reactor (SBBR)

B. The dissolved oxygen (DO) concentrations were maintained above 3mg/L in the SBBR. Experiments were conducted at room temperature. Minimum DO concentration was maintained 2-3mg/L throughout the pilot scale set up to maintain the biofilm under appropriate conditions [12].

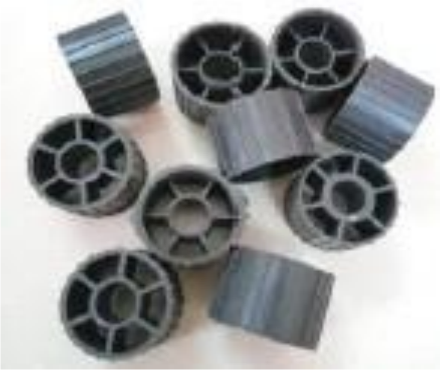
C. Activated sludge was obtained from a local municipal WWTP as a seeding material to the reactor. Wastewater was fed and discharged by means of Bernoulli's principle. The procedures of the reactor operation, such as feeding, aerating, settling and decanting, were controlled time to time by manually

D. There are two chambers in the reactor: Anoxic and Aerobic. First wastewater passes through the anoxic chamber where incoming wastewater carbon reacts with the nitrate and that converts into nitrogen gas. PVC virgin plastic media is used with 400 m2 /m3 surface area.

5. Experimental work :

Fig. 2 Development of Bio - Carriers(BioFilms)

Fig. 3 Ready Pilot Model (SBBR)



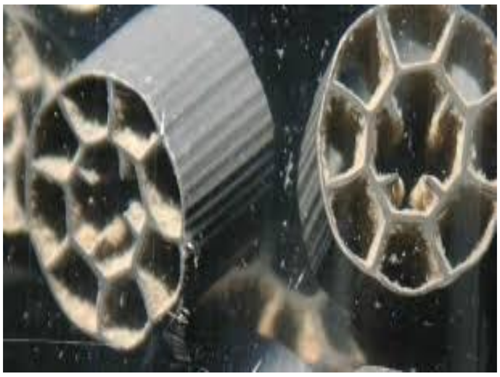


Fig. 4 Bio Films Media for (SBBR)

Average Inlet Characteristics Of Domestic Wastewater

Sr. No.	Parameters	Unit	Inlet Value
1	pH	---	7.0-9.0
2	TDS	mg/L	400-600
3	COD	mg/L	350-500
4	NH_3-N	mg/L	40-45
5	TN	mg/L	45-50

6. Experimental Procedure :

- ➔ SBBR will be operated at 6/24 h cycling periods on a day that consists of wastewater fill (30 min), reaction (4 h), settling (1 h) and draw (30 min), summed up to 6 h with the hydraulic residence time (HRT) of 7.5 h. For hydraulic residence time, at least 7h are proposed by Lopez-Lopez et al. [6] in treatment of domestic wastewater.
- ➔ In the sequencing batch operations, the reactors will be filled with domestic wastewater up to a total volume of 20 L and then both the aeration and mixing were started during the reaction phase. In the settling phase, the aeration and mixing were stopped and the mixed liquor was left to settle for 1 h. The supernatant (16 L) will be removed and the remainder was used for the next cycle in SBBR.
- ➔ A start-up period of about 4 weeks for biofilm growth on the carrier was followed by 12 weeks of testing in SBBR. The SBBR were operated for a period of 4 weeks to confirm the maturity of the biological treatment systems and to ensure that the steady state conditions were achieved. Steady state condition is defined as the period during which the effluent quality was relatively constant with regard to the parameters of COD and TSS.
- ➔ SBBR were subjected to 1 cycle (6 h) in 24h and the same cycle can be resumed 4 times for any failures.

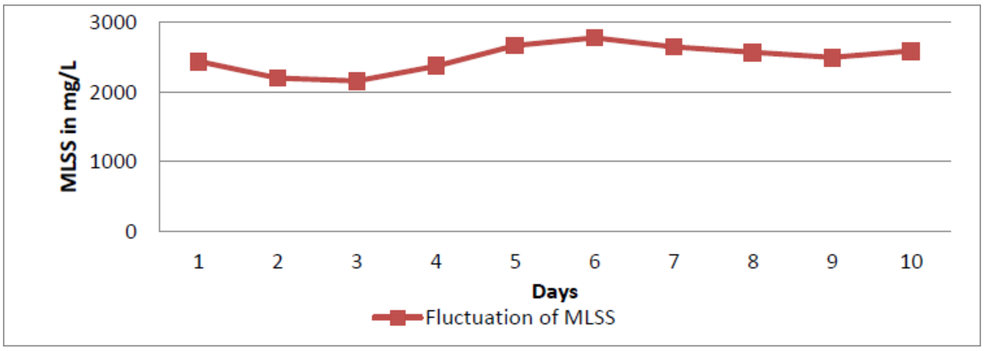
7. Bio Carriers :

- ➔ The Kaldnes K1 biofilm carrier elements are made of polyethylene and are shaped like small cylinders (nominal diameter of 9.1mm and a nominal length of 7.2mm) with a cross inside the cylinder and longitudinal fins on the outside. The Kaldnes carriers have a specific gravity of 0.96 with a specific biofilm protected surface area of 500m2/m3 bulk volume of carriers.The Kaldnes biofilm carrier element is illustrated in Figure beside.
- ➔ Microscopy of the biofilm media from several pilot and full-scale moving bed biofilm plants has shown sign of biofilm growth inside but not outside of the smooth plastic elements. The reason is believed to be the erosion caused by the frequent collisions between the pieces. Therefore, the biofilm surface area has been calculated based on the internal (protected) surface of the plastic elements. The available surface area (referred to the reactor volume) was changed according to the filling ratio. Protected surface is calculated as 200, 250 and 300m2/m3 for filling ratio of 40, 50 and 60%, respectively
- ➔ A well-designed Bio-carrier enables stable biofilm in the SBBR treatment, so that the void is not blocked by wastewater particles or excessive biofilm accumulation. Effective mixing/aeration combining a good carrier design leads to good system performance and low-maintenance requirements

8. Bio Fillings :

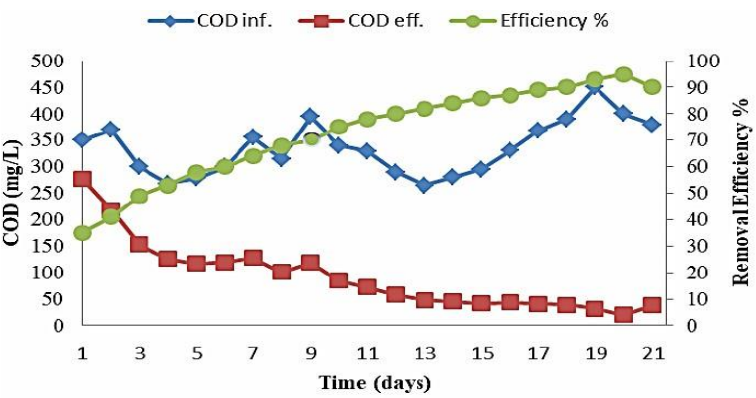
- The carriers are continuously mixed in the reactor and the whole reactor has homogeneous conditions. Due to shear forces from mixing/aeration, biofilm growth and detachment processes are balanced to maintain a relatively constant biofilm thickness at steady-state condition.
- Proper Air is required to develop the biofilm thickness in the bio-carriers.The biofilm thickness increases linearly with the total volume of air supplied to the system (R2 = 0.96).
- The biofilm thickness changes significantly with total volume of air supplied to the system ($p < 0.0001$). SBBRs with thinner biofilms are considered to be more efficient compared to those with thicker biofilms, likely due to lower mass fillings limitations associated with thin biofilms.

MLSS variations within the period of start-up



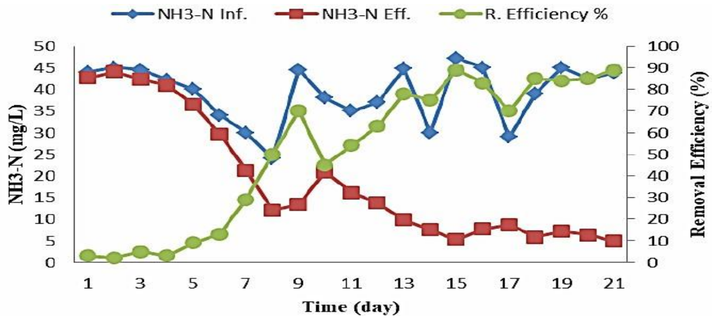
Shows that MLSS profile in operation SBBR. After 4 weeks of commissioning of the SBBR reactor MLSS concentration is achieved 2492.5±200 mg/L.

COD variations within the period of start-up



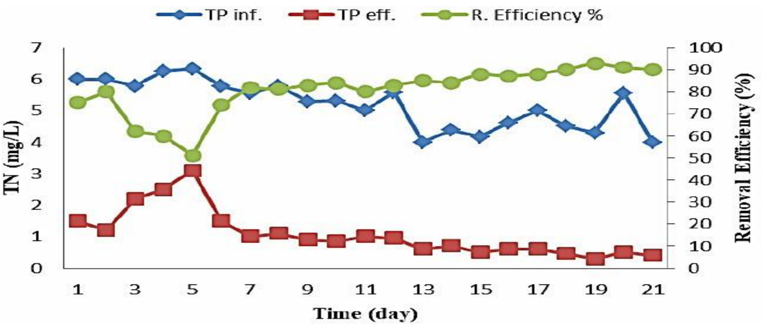
At the beginning stage during the start-up cycle, SBBR reduced up to 35 percent of COD, and the effluent concentrations were decreased by about less than 280 mg/L, as clear in Figure. The removal efficiency of COD was steadily increased as the acclimation period was extended after two weeks, with a stability efficiency of 85 –95 percent and an average effluent COD concentration of 36 mg/L. During the entire start-up phase, the COD removal efficiency in the reactor was nearly 95. percent, indicating that the reactor had achieved a successful start-up for COD removal.

NH3 -N variations within the period of start-up



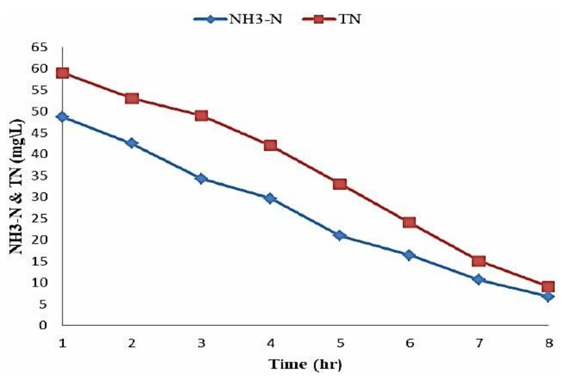
The variance of NH3 -N was close to that of TN, as seen in Figures (3 and 4), and the NH3 - N effluent concentration is varied clearly. The amount of ammonia nitrogen was steadily degraded firstly, probably due to the poor metabolism of Ammonia Oxidizing Bacteria. The NH3 - N effluent concentration then decreased from 44 mg/L to 5 mg/L, meaning that the reactor was efficient in the removal of nitrogen.

TP variations within the period of start-up

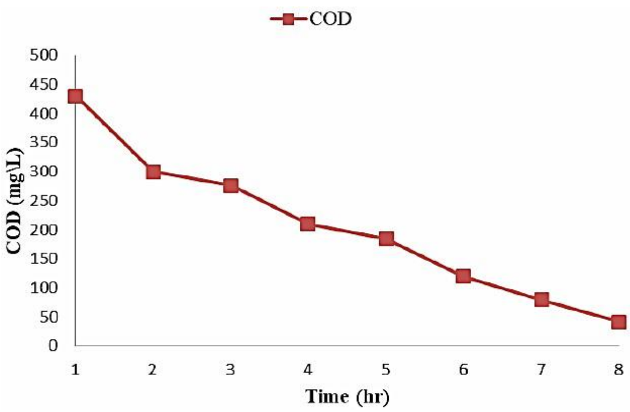


The Total Phosphorus (TP) concentration was reduced from 6 mg/L to 1.3 mg/L within the first two days., as shown in Figure. However, on the fifth day, the total phosphorus concentration effluent in the SBBR reactor was raised to 3.2 mg/L; afterward, the total238 phosphorus concentration effluent in the SBBR gradually decreased to less than 0.5 mg/L, and TP removal efficiency increased to 93.0 percent.

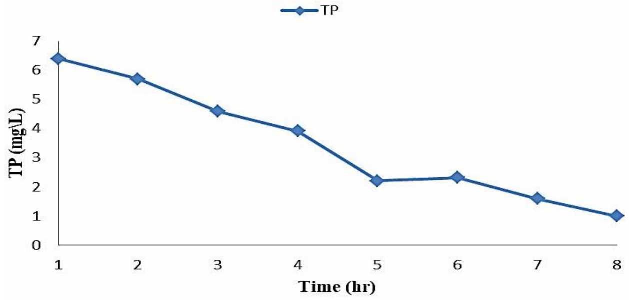
9. 2ND MODE CYCLE CHARACTERISTIC VARIATIONS WITH THE TIME PERIOD OF 8 HRS



COD variations with the time period of 8 Hrs



NH3-N variations with the time period of 8 Hrs



TP variations with the time period of 8 Hrs

10. Results & Discussion

SBBR System in Normal Operation to Remove Different Pollutants

- It is possible to divide the operation of SBBR into two conditions, start-up and steady-state. The system of SBBR worked in the start-up condition before the steady-state condition. When the removal of the rate of COD, NH3 -N, TN, and TP could be consistently held at 95 %, 89 %, 85 %, and 93 %, respectively, this indicates to the steady state condition is reached. The SBBR process was performed at steady-state in two different cycle operation modes, referred to as 1st, and 2rd cycle modes.

Cycle mode	No. of period per day	Fill (min)	Aeration (hr)	Settle (hr)	Draw (min)
1st Mode	Twice	15-30	4	1	15-30
2st Mode	Twice	15-30	8	1	15-30

- Every SBBR operation cycle mode is consisted of the fill, react and draw phases. The react time for any cycle mode was the total cycle excluded the times for the fill and draw, within two months of operation and acclimatization, the SBBR had reached a steady state. The average results of the third operation cycle mode for the SBBR system will be discussed in the sections below.
- The COD, NH3 -N, TP, and TN effluent concentrations were measured within the 2rd operation cycle mode for 8 hours of aeration in order to evaluate a more suitable aerobic period. The concentration of DO was recorded between 2.0 and 4.9 mg/L.
- The concentration of COD dropped significantly in the first two hours of the aerobic process, reaching 299 mg/L, After 8 hours, the COD concentration has decreased to 42 mg/L.
- The concentration of NH3 -N dropped significantly and reached 16.36 mg/L after 6 hours, meaning that the nitrifying bacteria were active.
- Since the conversion of NH3 -N to NO3 and NO2 , the concentration of Total Nitrogen did not change rapidly at the beginning. After 5 hours, the TN concentration had dropped slightly, and after 7 hours, it had dropped to 15 mg/L.
- The concentration of NH3 -N gradually decreased simultaneously, indicating that nitrification and denitrification were occurring at a similar time at this phase.

- In the early aerobic stages, the TP concentration dropped quickly, indicating that the polyhydroxy butyrate (PHB) accumulated in the body has been completely oxidized. After 5 hours, in the SBBR system, the Total Phosphorus concentration had stabilized at 2.25 mg/L, indicating that the phosphorus removal process had been accomplished.

- Aeration for a long time causes the bacteria to produce more PHB, which reduces their ability to remove phosphorus [Metcalf et al., 2003]. In the SBBR system, the 8 hours aerobic period is preferable due to the varying times for different reaction processes.
- The MLSS variation occurs due to variation in influential characteristics. The results show that SBBR is working better compared to SBR and MBBR due to better process performance as COD, NH3-N, TP and TN removal.
- The SBBR method proved to be effective in treating domestic wastewater in Basrah city. COD, NH3 -N, TN, and TP concentrations in the effluent were 42, 6.7, 9.0, and 1.0 mg/L, respectively, with the removal efficiency rates of 90.32 percent, 86.24 percent, 84.75 percent, and 84.38 percent.
- The COD, NH3 -N, TP, and TN effluent concentrations were measured within the 2rd operation cycle mode for 8 hours of aeration in order to evaluate a more suitable aerobic period. The concentration of DO was recorded between 2.0 and 4.9 mg/L.

FEED PRIMARY

TREATED WATER

Average Final Outlet Characteristics Of Domestic Wastewater

Sr. No.	Parameters	Unit	Final Outlet Value	Removal Efficiency
1	pH	---	7.0-7.5	-
2	TDS	mg/L	200-250	50-60%
3	COD	mg/L	25-35	90±5%
4	NH_3-N	mg/L	2-5	85±5%
5	TN	mg/L	10-15	80±5%

10. Conclusion

- In this research, the SBBR system has been used for domestic sewage treatment. The SBBR operation method has three cycle modes (first, second, and third). The following conclusions can be drawn from the tests and results conducted in the current study:
- The SBBR was designed to provide a compact and cost-effective treatment solution for wastewater compared to SBR and MBBR.
- The small scale 300 L/day SBBR prototype is working efficiently.As the wastewater characteristics varied, recovery took more time to reach steady state conditions for the SBBR.
- The MLSS variation occurs due to variation in influential characteristics. The results show that SBBR is working better compared to SBR and MBBR due to better process performance as COD, NH_3-N, TP and TN removal.

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