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Studies on Laboratory Scale Sequential Batch Reactor for Treatment of Domestic Wastewater

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ABSTRACT

Nowadays, huge amount of domestic and industrial waste is being discharge to the surface or groundwater which poses a great threat to the mankind. Hence, treatment of any kind of wastewater to produce effluent with good quality is necessary. In this regard, choosing an effective treatment system is much important. Sequential Batch Reactor (SBR) holds a special place in the wastewater treatment which is a modified version of activated sludge process. An SBR operates in a true batch mode with equalization, aeration and sludge settling, all occurring in the same tank. The removal of organic load in the reactor mainly depends on the duration of reaction phase, so it is essential to determine the optimum duration of reaction phase. In the present study, an attempt was made to optimize the duration of the reaction phase in SBR for the treatment of domestic wastewater and removal efficiency of COD, BOD and SS were studied. To optimize the duration of reaction phase in SBR, a 100-litre capacity laboratory scale model was fabricated and operated for 100 cycles for various reaction phases. The percentage removal efficiency of BOD, COD and SS for various reaction periods was calculated and the graph between reaction percentage removal efficiency of BOD, COD and SS were drawn, the results were utilized to determine the optimum reaction period for effective treatment of domestic wastewater with high removal efficiency using SBR.

INTRODUCTION

The domestic and industrial wastewater, whether treated or untreated, is usually disposed off into nearby natural water courses. Organic matters present in the wastewater decompose and create unsightly conditions and unpleasant odours. These decomposable organic matters present in the wastewater also consume dissolved oxygen from the stream when getting oxidized and thereby killing the aquatic organisms. In addition to this, the wastewater may also contaminate the stream with pathogenic microorganisms. It also contains toxic compounds that are harmful for domestic uses. For these reasons, even though domestic wastewater is 99% water, it requires treatment and proper disposal to avoid environmental pollution.

The sequential batch reactor (SBR) is the most promising and viable of the proposed activated sludge modifications for the removal of organic carbon and nutrients. Due to its simplicity and flexibility of operation, it has become increasingly popular for the biological treatment of domestic and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low and/or intermittent flow conditions. The most common (aerated) SBR is a fill-and-draw activated sludge system for wastewater treatment. Equalization, aeration and clarification can all be performed in a single batch reactor. This equipment has also been used for anaerobic (non-aerated) digestion of industrial and domestic wastewaters. The determination of the influent characteristics and effluent requirements, site specific parameters such as temperature, and key design parameters such as nutrient-to-biomass ratio, treatment cycle duration, suspended solids and hydraulic retention time are imperative to establish the operation sequence of the SBR. It allows calculating the number of cycles per day, number of basins (batches), decanting volume, reactor size, and detention times. Sequencing batch reactor is a modification of activated sludge process, which has been successfully used to treat domestic and industrial wastewater. The main advantages are easy operation, low cost, handling hydraulic fluctuation, no need for settling tank and sludge recycling as well as organic load without any significant variation in removal efficiency. The SBR process operates in a series of timed steps, reaction and settling can occur in the same tank, eliminating the need for a final clarifier. The objective of this study is to treat the domestic wastewater in a SBR by varying COD, BOD and SS for various reaction times (Durai et al. 2011).

MATERIALS AND METHODS

Wastewater characteristics: The domestic wastewater sample was collected from the Kongu campus sewage collection tank. A laboratory scale model of SBR was fabricated having 100-litres capacity and used to study the performance for the treatment of domestic wastewater. The wastewater characteristics such as pH, BOD, COD, total solids, volatile and suspended solids and alkalinity were analysed and the results are given in Table 1.

Operational procedure of SBR: The operation of the SBR is consisted of five steps: fill, react (aeration), settle (sedimentation/clarification), draw (decant) and idle. Three and half (3.5) litre of 10 g/L acclimatized bio-sludge was inoculated in SBR system, and domestic wastewater was added (final volume of 20 litre) within 2 hour (fill step). During the feeding of domestic wastewater, the system has to be fully aerated. The aeration was then continued for another 19 hours (react step: aeration). Aeration was then shut down for 3 hour (settle step: sedimentation/clarification). After the bio-sludge was fully settled, the supernatant was removed within 0.5 hour (draw step: decant) and the system had to be kept under anaerobic conditions (idle step) for 0.5 hour. After that, fresh domestic wastewater was filled into the reactor to the final volume of 20 litre and the above operation program was repeated. For the removal of excess bio-sludge to control the stable bio-sludge concentration of the reactor, the excess biosludge was wasted from the bottom of the reactor during the idle step.

Bacterial seeding: The reactor was filled with fresh water and aerated for one day. Five kg of fresh cow dung was mixed with water to form slurry. The solids in the slurry were allowed to settle down. After 5 minutes of settling, the supernatant enriched with heterotrophic bacterial culture was transferred into the aeration tank. The cow dung and domestic waste water were added to the reactor for 20 days to develop the microbial culture and nutrient addition. Five litres of bacterial seed and 25g of urea were added to reactor daily (for nutrient purpose) and aerated for 10 days. 10% of raw domestic wastewater was added into the reactor initially and then the feeding rate was increase gradually for the acclimation of bacterial culture. The parameters such as COD, pH and MLSS were checked daily. After 20 days it was observed that the designed MLSS of 3500mg/L was acclimated in the reactor (Rajesh babu et al. 2009).

Acclimatisation of microbial culture: Acclimatisation is the time required for the microbial culture to get accustomed to the conditions present in the particular wastewater treatment plant (aeration tank) and carry out the process of biodegradation of the substrate to the harmless final products, *viz*., water and carbon dioxide. The time required for acclimatisation depends primarily on the factors like BOD and COD values, DO, pH, temperature, micronutrients, etc. The bacterial seed added should be substrate-specific, in that it should be able to degrade the particular organic substances present in the waste stream. The acclimatisation time could be as low as one week for easily degradable wastes such as sewage/domestic waste, to as high as eight weeks in case of complex wastes (Shiva Prasad et al. 2011).

Table 1: Influencing characteristics of domestic wastewater.

Sl.No	Parameters	Units	Values
1.	pH	-	7.5-8.5
2.	Total solids	mg/L	1600-1850
3.	Suspended solids	mg/L	500-550
4.	Dissolved solids	mg/L	1100-1300
5.	Alkalinity	mg/L	1125-1250
6.	COD	mg/L	270-290
7.	BOD	mg/L	155-165

Factors affecting the SBR process: The effective and efficient operation of the SBR process depends upon the steady state condition. The major factors of SBR performance include organic loading rate, HRT, SRT, DO and influent characteristics such as COD, solids content and C/N ratio. Depending on controlling of these parameters, the SBR can be designed to have functions such as carbon oxidation, nitrification, denitrification and phosphorus removed. SBR is considered to be a suitable system for wastewater treatment in small communities.

***Dissolved Oxygen*:** It is the primary criteria for maintaining aerobic environment in the sequencing batch reactor process. The amount of oxygen transferred into the aeration tank theoretically equals the amount required by the microorganisms to oxidize the organic matter and maintain the residual DO operating levels. The DO level in the aeration tank is dependent on the following factors: (1) Organic load/ strength of the incoming waste water, (2) The MLSS concentration in the aeration tank, (3) Oxygenation capacity of the aeration device (diffusers), (4) The mean cell residence time i.e., retention time of the wastewater in the aeration tank, (5) The quantity of activated sludge. A decrease in the DO level results in an increase of the filamentous organisms, causing the phenomenon known as 'sludge bulking', whereas over-aeration (increase in the DO levels) may cause non-filamentous foaming on the surface of the aeration tank. The DO level should be maintained in the range of 1.5 to 4.0 mg/L in all areas of the aeration tank, with the average value being about 2 mg/L. Dissolved oxygen in the tank helps in detecting anaerobic conditions, excessive turbulence, and decrease in the SVI values the filamentous growth. Increase in the DO level is a measure to correct the floating sludge, excess amount of pin-flocks and turbidity in the sewage stream.

***Biochemical oxygen demand (BOD)*:** The BOD value of the influent stream helps in assessing the organic load of

Table 2: The chemical analysis of raw and treated effluents.

Reaction	Raw Effluent				Treated Effluent				% COD	% BOD	% SS
time (hrs)	pH	(SS) mg/L	COD mg/L	BOD mg/L	pH	SS mg/L	COD mg/L	BOD mg/L	removal mg/L	removal mg/L	removal mg/L
16	7.8	400	280	156	7.6	32	80.45	21.75	71.25	88.31	91.85
14	8.2	450	285	160	7.9	37	85.35	22.85	70.20	88.22	91.78
12	8.4	390	290	158	8.2	34	94.54	23.45	67.52	87.10	91.20
10	7.4	420	285	160	8.0	37	104.23	28.65	63.42	83.50	91.17
8	8.2	410	278	165	7.8	52	112.84	32.54	59.42	79.10	87.32
7	8.5	430	280	155	8.3	64	120.65	38.52	56.90	75.15	85.10
6	8.6	370	283	158	8.1	77	135.25	45.23	52.38	71.37	79.18
5	8.3	390	275	154	7.9	85	145.78	51.23	47.10	66.73	78.20
4	8.2	400	270	160	8.1	120	156.27	57.23	42.12	63.50	70.00
3	8.1	390	280	158	7.7	149	165.25	63.25	41.00	59.97	61.70
2	8.4	390	285	162	7.9	203	178.00	68.36	37.60	56.00	48.00

the aeration tank. If the desired reduction in the BOD level does not take place due to the excess loading to the aeration tank, it can be rectified by controlling the rate of flow of wastewater by operating the controlling valves. This will result in an increase in the detention time of the effluent in the aeration unit to facilitate better BOD removal.

***Microorganisms*:** A microscopic examination of the wastewater/sewage in the aeration tank reveals the presence of various groups of microbes in the system. A close monitoring of the population of these various microbial groups help in controlling the process so as to give the best overall performance. A pie-dominance of the filamentous forms (thread-like forms), amoeboid and rotifers indicate an unhealthy, malfunctioning system that gives rise to various operational problems like sludge bulking, reduction in the oxygen levels, floating sludge, pin-flocks, etc. On the other hand, larger population of free swimming and attached protozoans called ciliates (floc-formers) are an indication of a healthy and well operated process. Addition of stoichiometric quantities of chlorine and hydrogen peroxide to the sludge are the methods by which the population of filamentous forms can be reduced. Increasing the sludge age, addition of nutrients like nitrogen and phosphorus, and increasing the rates of air supply are the other corrective measures for reducing filamentous forms.

***Food to microorganisms ratio (F/M ratio)*:** The F/M ratio is considered essential for the efficient operation of the plant, and is expressed as F/M = BOD applied per day into the aeration tank/amount of MLSS or MLVSS in the tank. This ratio helps in detecting the DO depletion and the resulting potential for filamentous bulking in the aeration tank.

***Sludge wasting*:** The excess activated sludge produced each day must be wasted to maintain a given F/M ratio or Mean Cell Residence Time (MCRT). This excess sludge is wasted by waste sludge disposal pumps into sludge drying beds. The amount of sludge to be wasted depends on (1) Flow rate and strength of the influent stream, (2) MLSS levels in the SBR, and (3) The sludge age.

***Oxygen uptake level*:** Microorganisms in the sequencing batch reactor process use oxygen as they consume the food matter. The rate at which they use oxygen can be taken as a measure of the biological activity. A high Oxygen Uptake Rate (OUR) indicates a high level of bioactivity, and vice-versa. The value of OUR is obtained by taking a sample of 'mixed liquor' saturated with DO, and with the help of a DO probe, measuring the decrease in the DO over time. The results are reported as mg of O_2/L min/hr.

***Mixed liquor suspended solids (MLSS)*:** The MLSS is the amount of solid particulate matter present in the mixed liquor, i.e., the mixture of activated sludge and raw wastewater. The MLSS is used as an important parameter to design and control the operation of the aeration system. The two factors to be considered in this respect are the MLSS concentration in the aeration tank and the settling ability of the mixed liquor. Maintenance of the MLSS level is very important for optimum treatment of the incoming effluent stream. If the MLSS concentration decreases, the sludge wasting should be decreased, to increase the concentration of MLSS in the aeration unit. Conversely, if the MLSS concentration increases, the wasting of sludge is also increased to restore the balance of MLSS in the tank.

***Sludge volume index (SVI)*:** Sludge volume index is the ratio of the percent of settled volume of sludge to the percent weight of MLSS in grams. It is a measure of the settling ability of the activated sludge, and indicates the degree of concentration and the physical state of the sludge. An SVI range of 80 to 150 indicates proper settling of the sludge, and the healthy operation of the plant. When the SVI is more than 150, it indicates that the sludge settlement is not proper, and at a value of 200, the problem of sludge bulking begins. The methods of control of SVI values are by controlling the MLSS concentration and flow of effluent in the aeration tank. An SVI value above 150 means the amount of sludge wasted has to be increased, and the quantity of 'return activated sludge' from the settling tank should be reduced.

pH range: The pH in the aeration tank should be maintained at a near neutral value for the proper operation of the plant. An effluent having neutral pH has the following advantages viz., (1) a neutral pH provides the conditions for the best metabolic activity and the ability to withstand shock loading, (2) oxygen uptake is optimum at a pH range of 7.0 to 7.4 and, (3) the BOD removal efficiency decreases as the pH moves away from this range. If the changes in the pH values are gradual, there will not normally be any serious damage to the process. However, the sudden change in the pH values, such as occurring due to addition of certain type of industrial wastes (highly acidic or alkaline) is most dangerous, and can result in killing some or all the microorganisms. It is for this reason that the pH should be continuously monitored at the inlet point of the plant. If it is detected at this point, the operator may be able to utilize the detention time in the equalization tank to neutralize the effluent.

***Toxic loading*:** The toxic loads are defined as those elements or compounds, which enter the treatment plant in sufficient concentration to kill the resident population of microorganisms, and cause temporary system collapse. The typical examples of such toxic loads are the discharge of cyanides and heavy metals such as chromium from metal processing industries. Proper methods for handling the toxic loads involve (1) dilution of the waste and holding all the sludge possible in the aerator i.e., the MLSS concentration is maintained at a high level, to provide a cushion against the toxins, (2) contain the waste in some spare tank, and then gradually bleed it through the process and, (3) the toxic waste should be diverted through various bypass arrangements.

Process operational problems: The three most common problems encountered in the operation of an activated sludge process are (1) bulking sludge, (2) rising sludge and, (3) foaming.

***Bulking sludge*:** The bulking sludge is one that has poor settling characteristics and poor compactability. Two main types of sludge-bulking problems have been identified. One is caused by growth of filamentous organisms (filamentous bulking), while the other is due to the condition known as 'bound water' in which the bacterial cells comprising the 'floc' swell by the absorption of water (non-filamentous bulking). This reduces the density of the floc causing it to float on the surface of the tank. Filamentous bulking is caused by low DO levels in the aeration tank, insufficient amount of nutrients like nitrogen and phosphorus, widely varying organic loading (waste of varying strength), and low F/M ratio. Over-aeration of the tank contents and presence of certain toxic compounds in the waste stream also cause non-filamentous bulking.

Bulking can be controlled by monitoring the optimum DO level in the aeration tank by adding regular dosage of sufficient quantities of nutrients, preventing wide fluctuations in pH and organic loading, and maintaining optimum range of F/M ratio.

***Rising sludge*:** Occasionally, sludge that has good settling characteristics is seen to rise to the surface after relatively short settling period. The cause of this phenomenon is usually denitrification in which case the nitrates and nitrites in the wastewater are converted into nitrogen gas. As the gas is formed, it gets trapped in the sludge mass and makes it rise to the surface. Rising sludge can be differentiated from bulking sludge by the presence of small gas bubbles attached to the floating solid particles. This can be overcome by (1) increasing the rate of sludge wasting from the settling tank to reduce its detention time which prevents denitrification, (2) decreasing the rate of flow from the aeration tank to the settling tank, and (3) preventing nitrites and nitrates in effluent.

***Odour*:** A healthy, well-monitored plant can be operated with the minimum amount of odour. However, odours occasionally develop from the sources like septic wastewater, waste from certain septic industrial processes, accumulated screenings and grit, sludge thickening/digestion tanks and sludge drying beds, etc. This problem can be overcome by (1) maintaining aerobic conditions by increasing the rate of aeration and mixing, (2) controlling anaerobic microbial growth by periodic disinfection or pH control, (3) preventing excessive turbulence in the aeration tank, and (4) increasing the frequency of sludge and scum wasting.

RESULTS AND DISCUSSION

Performance of SBR: Calculated amount of raw domestic wastewater was added to the reactor daily in order to maintain an F/M ratio of 0.3. The mean cell residence time of 10 days was maintained by controlling the wasting of mixed liquor from the reactor. The steady state parameters maintained were mixed liquor suspended solids concentration (MLSS), SS, pH, COD and dissolved oxygen (DO). The DO was maintained in the range of 2-2.5 mg/L. The reactor was operated for 110 cycles containing fill, react, settle and draw phases. Treatability of SBR for various reaction times from

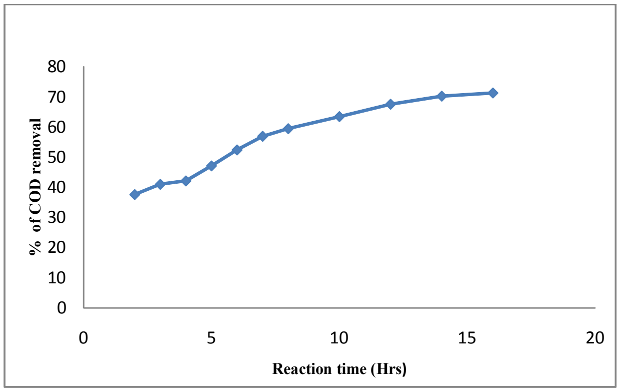

Fig. 1: COD removal effciency.

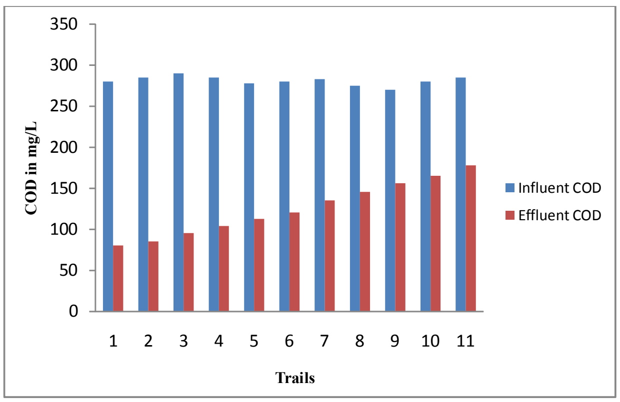

Fig. 2: Influent and effluent concentration of COD for different reaction times.

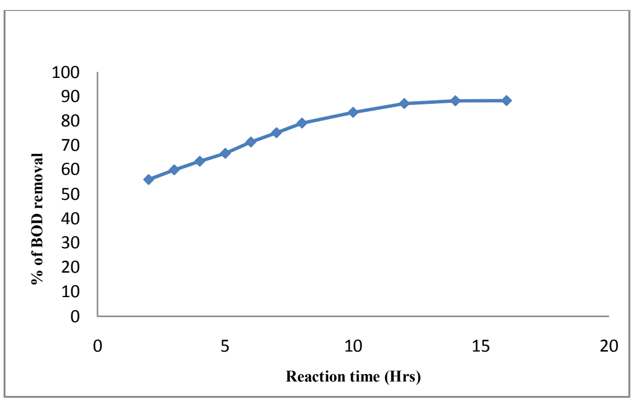

Fig. 3: BOD removal effciency.

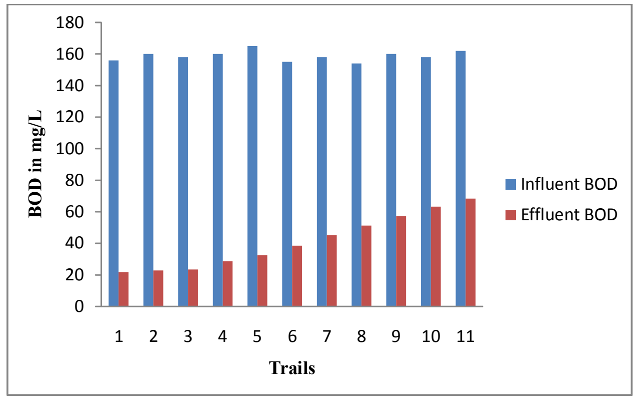

Fig. 4: Influent and effluent concentration of BOD for different reaction times.

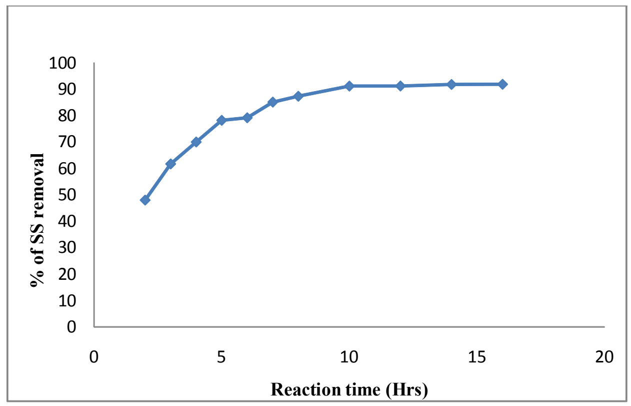

Fig. 5: SS removal effciency.

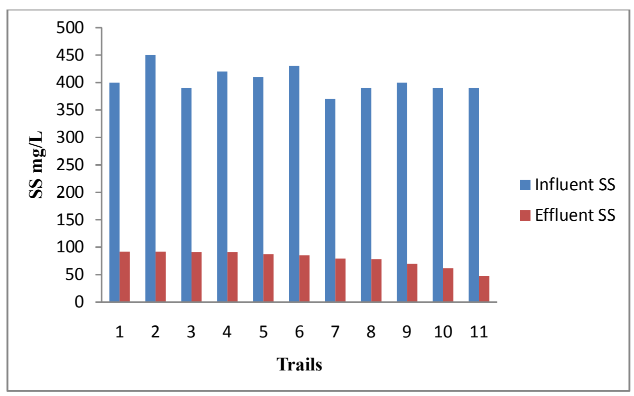

Fig. 6: Influent and effluent concentration of SS for different reaction times.

16-20 hrs was studied; 10 number of operation cycles were done for each reaction time. The results of the analysis of the raw and treated effluents are given in Table 2. The percentage removal efficiency of COD, BOD and SS for various reaction times was studied and plotted graphically in Figs. 1, 2, 3, 4, 5 and 6. From the analysis, it can be seen that the removal efficiency of COD, BOD and SS is 71.25%, 88.31% and 91.85% respectively as given in Table 2.

CONCLUSION

The SBR is a cost effective and reliable technique for the removal of domestic wastewater. It provides provision for flexibility in variation of operating conditions to achieve desired results for it is time oriented rather than space oriented. Advantages of SBR are that equalization, primary clarification, biological treatment, and secondary clarification can be achieved in a single reactor vessel. The pollutant removal efficiency of SBR system has shown high removal efficiency for BOD, COD and SS. The SBR is reported to be feasible for almost all kinds to organic wastewaters for the temperature greater than 20°C. The SBR provides simplicity in process, construction and requires less operational time. So it can be fruitful treatment for the intermittent flow sources such as colonies and institutions, etc. and it also provides very less treatment cost due to the elimination of pumping for recycling the sludge.

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