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Sequencing Batch Reactor (SBR) Treatment for Simultaneous Organic Carbon and Nitrogen Removal- A Laboratory Study

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The performance of a laboratory-scale Sequencing Batch Reactor (SBR) has been studied in aerobic-anoxic sequence for simultaneous organic carbon and nitrogen removal. The reactor was operated under three different variations of aerobic-anoxic sequence, viz. 4+4, 5+3 and 3+5 hours with input solutions of soluble COD (SCOD) level 1000±100 mg/L and initial ammonia nitrogen of 40 and 90 mg/L. It has been observed that 85 to 92% of SCOD removal would be possible at the end of 8.0 hour of overall reaction period, irrespective of the length of the aerobic react period. In the case of 4+4 hour operating cycle, reasonable degree of nitrification (88-100%) and denitrification (73-75%), along with 91-94% of organic carbon removal have been achieved, which has been considered to be the optimum performance of the reactor.

Key words : *Sequencing Batch Reactor, organic carbon oxidation, nitrification, denitrification, operating cycle, aerobic, anoxic, reaction time.*

Introduction

A sizeable number of options for biological reactors have been developed for the treatment of municipal and industrial wastewater through the ages, out of which Sequencing Batch Reactor (SBR) is being applied with a view to replace continuous flow activated sludge process in a more economical manner. It is considered to be an alternative of activated sludge process (ASP), which operates in fill and draw mode for treatment of biodegradable organic substances. It is reported that the treatment in SBR is economical than conventional continuous mode activated sludge process in the tune of 20%, being equally efficient from the viewpoint of organic carbon removal.[1]

In the recent period, SBR has received considerable attention, though the theoretical fact of the process is not a novel one[2]. Irvine and Busch (1979)[3], in their pioneering research established that SBR could be an excellent alternative of conventional activated sludge process for both municipal and industrial wastewater treatment. It can also be used as a package treatment unit, particularly for simultaneous treatment of organic and nitrogen bearing waste in a single reactor system.

SBR is a periodic fill and draw type activated sludge process in which the reaction tank is filled with wastewater for a discrete period of time known as fill time. The liquid is then allowed to undergo biochemical reaction in presence of active microorganisms under aerobic and/or anoxic condition in a batch mode of operation, which is known to be the react time. In the subsequent phase, the mixed liquor is allowed to settle and the clarified effluent is withdrawn after a time period known as settle period. Thus, each SBR encompasses the function of equalization, aeration and sedimentation in the same vessel, where as in continuous flow systems the above operations are conventionally done in separate individual tanks.

Irvine and Palis (1985)[4] conducted an extensive study on removal of nitrogen in a low-loaded laboratory-scale single tank sequencing batch reactor of 5.0L capacity. Nitrification was favoured to the reactor by autotrophic nitrifiers for a simulated domestic rural wastewater under both continuous aeration and alternating aerobic/anoxic sequence. In another relevant investigation, Mekonen *et. al.* (2001)[5] achieved successful biological denitrification of high nitrate containing solutions (40-250 mg/L as N) by introducing ethanol as an external carbon source. The COD/N ratio was found to be optimum at 2.0 bringing the effluent nitrate to acceptable levels and also to achieve 85.7-91.5% reductions. Organic carbon was required for both energy and synthesis of denitrifiers and accordingly they have found that about 89% of COD removal took place due to uptake of organic carbon for their metabolic requirement. In their experimental work, it was also revealed that anoxic reaction time of 3, 5 and 7 hours would be required for the sample having nitrate concentrations of 40-160, 200 and 250 mg/L respectively. Mahvi *et. al.* (2004)[6] carried out a pilot scale study on removal of nitrogen from synthetic and domestic wastewater in a continuous flow SBR and they obtained a total nitrogen removal of (70-80%) and TKN removal of (85-95)%.

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Sequencing Batch Reactor (SBR) treatment

SBR technology is being successfully applied for treatment of landfill leachate[7], phenolic effluent[2], oilfield wastewater[8], slaughterhouse effluent[9], milking parlour effluent[10], dyeing wastewater[11] and various other industrial wastewaters[12]. However, the feasibility of SBR application has neither been explored nor very much tried in India.

In the present investigation, an attempt has been made to examine the efficacy of SBR technology for simultaneous removal of soluble carbonaceous organic matter and ammonia nitrogen from a synthetic wastewater.

Materials and methods

Experimental set-up

The experimental work was carried out in a laboratory-scale SBR, made of Perspex sheet of 5 mm thickness, having 20.0 L of effective volume. 750 mL of pre-acclimatized seed of mixed nature (heterotrophs, nitrifiers, denitrifiers) was added to 2.0 L of raw sewage obtained from a nearby sewage treatment plant in the reactor to perform the necessary experiments. Oxygen was supplied through belt driven small air compressor. A stirrer of 0.3 KW capacity was installed at the center of the vessel for mixing the content of the reactor. Air supply was provided during aerobic phase of react period. However, during the anoxic phase the stirrer was allowed to operate for mixing purpose. A timer was also connected to compressor for controlling the sequence of different react period. Oxygen was supplied in the reactor through strainer type perspex diffuser, placed at the bottom of the reactor. A schematic diagram of the experimental set-up is shown in the **Fig 1.**

Experimental procedure

The cycle period for the operation of SBR was taken as 10 hour, with a fill period of 0.5 hour, overall react period of 8.0 hours, settle period of 1.0 hour and idle/decant period 0.5 hour. The overall react period was divided into aerobic and anoxic react period in the following sequences.

Combination – 1 : 4 hour aerobic react period and 4 hour anoxic react period.

Combination – 2 : 5 hour aerobic react period and 3 hour anoxic react period.

Combination – 3 : 3 hour aerobic react period and 5 hour anoxic react period.

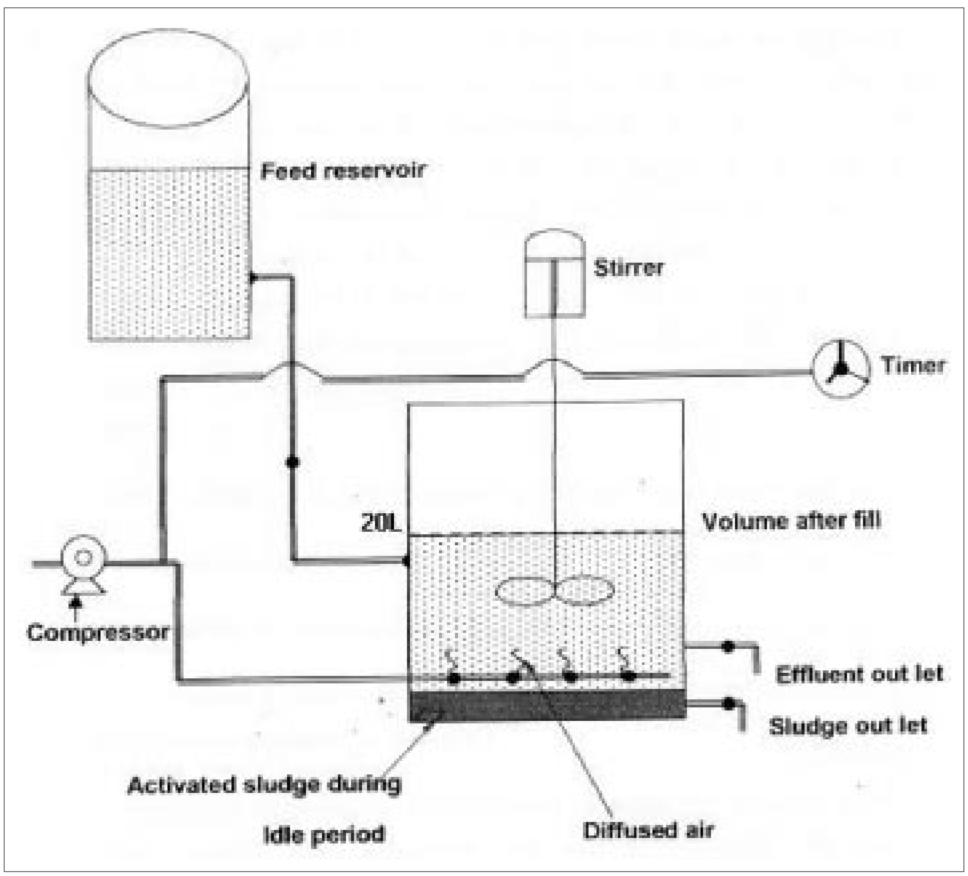

Fig. 1 : A schematic diagram of the experimental set-up

During the time course of the study, 100mL of sample was collected from the outlet of the reactor at every 1.0hour interval, on completion of the fill period. The samples were analyzed for the following parameters, viz. pH, alkalinity, DO, MLSS, MLVSS, COD, NH_4^+-N, NO_2^--N and NO^-_3N as per the methods described in Standard Methods[13]. The pH of the solution was measured by a digital pH meter (Systronics, India make). NH_4^+-N, NO_2^--N and NO_3^-- N were estimated by respective ion selective electrodes in Orion ISE, meter. COD was analyzed by closed reflux method using dichromate digestion principle and HACH, USA digester. Dissolved oxygen (DO) was measured electrometrically by digital DO meter (Systronics, India make).

Results and discussion

The performance of the present study was carried out taking a synthetic wastewater having an average initial soluble chemical oxygen demand (SCOD) of 1000mg/L and ammonia nitrogen (NH_4^+-N) concentration of 40 and 90 mg/L.

Removal of carbonaceous matter

Organic carbon, which is the source of energy for microbial metabolism, has been estimated in terms of chemical oxygen demand (COD). In the case of a particular experiment, carried out with an initial SCOD of 978.65 mg/L and initial NH_4^+-N concentration of 34.56 mg/L, it has been observed that the major fraction of SCOD removal (73.34%) took place during aerobic react period. In the anoxic phase, further SCOD removal has been noticed to the extent of 91.5% (**Fig.2**). A similar trend of removal pattern was also observed when initial NH_4^+-N concentration was increased to 86.42 mg/L as N with initial SCOD of 1017.32 mg/L in a separate set of experiment. SCOD removal or in other words, organic carbon utilization during the anoxic react period was noticed, perhaps due to the following reasons : i) organic carbon utilization by heterogens in the presence of some residual dissolved oxygen especially at the initial phase of anoxic react period and ii) organic carbon utilization by the denitrifiers in the anoxic phase for their metabolic requirement. It is revealed from **Fig.2** and **Fig. 4** that SCOD level has decreased rapidly during aerobic react period as compared to its rate of removal during anoxic condition due to dominance of organic heterotrophs. When the react period was changed into 5 hour aerobic followed by a reduced 3.0 hour anoxic, a marginal improvement in respect of SCOD removal (77-78%) was observed due to enhanced aeration time. On the other hand, when the react period was subsequently changed to 3.0 hour aerobic period followed by 5.0 hour anoxic period, a marginal decrease in SCOD removal was noticed (69%). However, at the end of 8.0 hour of total react period, about 83±2% SCOD removal was observed under identical input substrate condition taking all alternative combination of experimental sets.

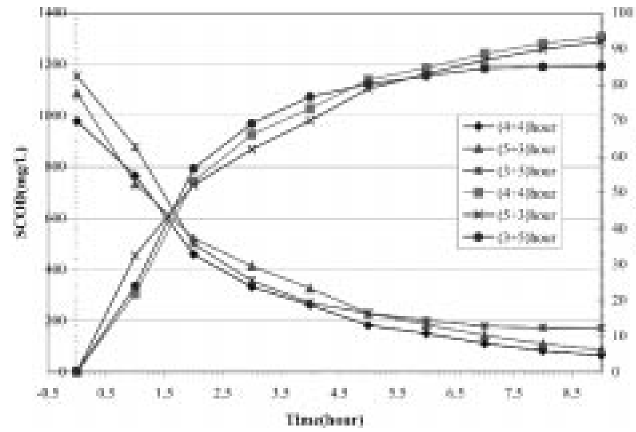

Fig. 2: Carbon oxidation profile {Initial SCOD (Tentative)= 1000mg/L; Initial NH_4^+-N (Tentative)= 40mg/L}

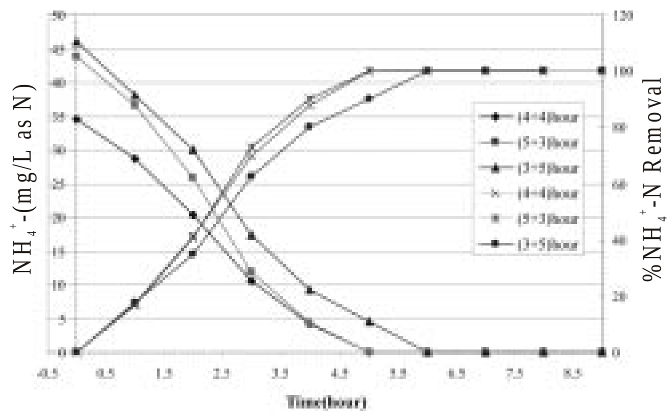

Fig. 3: Ammonia oxidation profile {Initial SCOD (Tentative)= 1000mg/L; Initial NH_4+-N (Tentative)= 40mg/L}

Ammonia oxidation

Ammonia oxidation took place due to the presence of previously acclimatized nitrifying organisms within the reactor. The NH_4^+-N level at different time periods for different combinations of react periods and initial NH_4^+-N concentration are exhibited in **Fig.3** and **Fig. 5.**

Considering the cycle period of 4 hour (aerobic) + 4 hour (anoxic), it has been observed that at the end of aerobic phase of reaction, nitrification was maximum when initial NH_4^+-N was approximately 40 mg/L as N. The ammonia oxidation was occurred in two phases. A fraction of ammonia was assimilated by cell-mass for synthesis of new cell during carbon oxidation. The dissimilatory removal of ammonia depends on the population of nitrifiers and oxidation time. The descending trend of ammonia removal for higher level of initial concentration of NH_4^+-N was mainly due to limitation of enzymatic metabolism of nitrifiers. When the reactor system was operated in 5 hour (aerobic) + 3 hour (anoxic) mode of react cycle, an overall improvement of ammonia oxidation (89.33% to 100 percent for

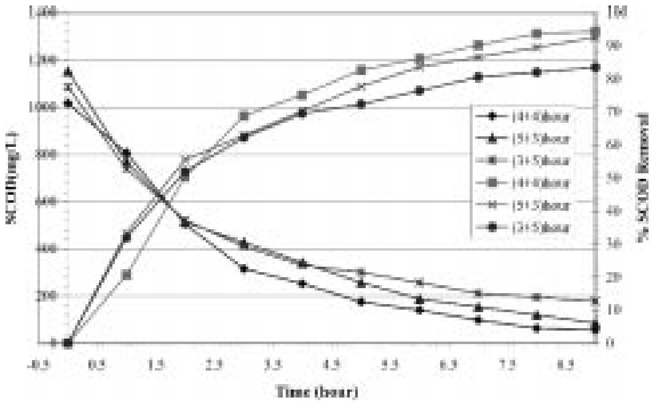

Fig. 4: Carbon oxidation profile {Initial SCOD (Tentative)= 1000mg/L; Initial NH_4^+-N (Tentative)= 90mg/L}

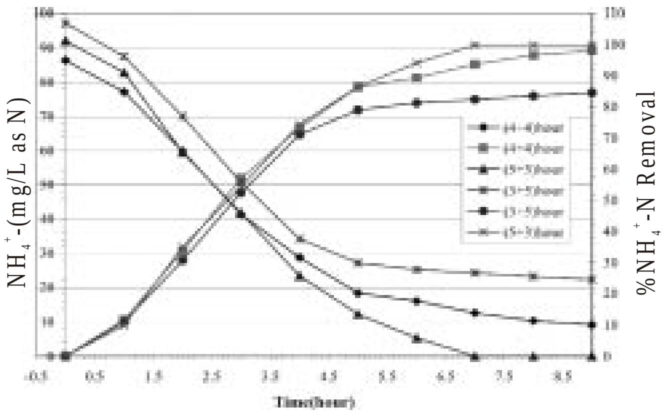

Fig. 5: Ammonia oxidation profile {Initial SCOD (Tentative)= 1000mg/L; Initial NH_4+-N (Tentative)= 90mg/L}

initial NH_4^+-N of 90 mg/L as N) was observed. The results reveal the fact that the extension of aeration period helped to enhance the oxidation efficiency for the present system.

This observation is also corroborated by the results obtained, when aerobic period was reduced to 3.0 hours. The ammonia oxidation reduced to 62.5% and 17.8% corresponding to NH_4^+-N value of 46.09 mg/L and 97.34 mg/L respectively, at the end of aerobic react period.

Nitrite and nitrate level in the reactor

Ammonia was converted into nitrate (NO_3^-) through an intermediate product as nitrite (NO_2^-) by the process known as nitrification. The essence of effective nitrification lies with high degree of nitrate (NO_3^-) formation and its recovery. However, unless nitrite (NO_2^-) is formed substantially by the autotrophic nitrosomonas, through utilization of NH_4^+-N as the substrate, the nitrate level cannot be elevated in the reactor. The kinetic profiles for various forms of nitrogen (NH_4^+-N, NO_2^- - N and NO_3^- - N) are shown in **Fig.3, 5, 6** and 7. The maximum nitrite level was observed in between 2.5 to 3.0 hour of react period. The peak nitrate (NO_3^-) level was found beyond 3.0 hour and close to 4.0 hour of aeration period, which was the terminal time for aerobic react phase. A time lag for maximum nitrate formation to the tune of one hour was also noticed after obtaining the maximum NO_2^- -N level in the reactor. For a cycle time of 5.0 hour (aerobic) + 3.0 hour (anoxic) mode, the formation of NO_3^- showed a time dependent factor, as the peak was found at the end of 5.0 hour.

The enhancement in $NH4^+$-N oxidation was possible due to higher aeration time, which reiterates the proposition given in literature.[14] In the **Fig.7**, after 4.0 hour of aeration period, the NO_3^- level was shown as 36.88 mg/L corresponding to initial NH_4^+-N level of 86.42 mg/L and NO_3^- concentration of 10.32 mg/L respectively. On the other hand, as shown in **Fig.7**, after 5.0 hours of aerated react period, NO_3^- - N concentration in the reactor was found to be 61.37 mg/L against an initial NH_4^+-N and NO_3^- concentration of 92.12 and 15.5 mg/L respectively. The maximum NO_3^- concentration for 3.0 hour of aerobic react phase was found to be 28.29 mg/L for the initial NH_4^+-N concentration of 97.34mg/L and NO_3^- level of 14.58 mg/L. The experimental results clearly indicate the necessity of longer aeration period for achieving maximum utilization of ammonia by the nitrifiers.

Denitrification kinetics

Denitrification in any biological reactor can be achieved only when dissolved oxygen (DO) level in the reactor is very low or even absent (<1.0 mg/L). Such anoxic environmental condition can be maintained in SBR system when supply of air is shut off. In the present investigation, the anoxic period was started progressively just after the supply of air was taken off. Both nitrification and denitrification profiles at different time intervals from the starting phase are shown in **Fig.6** and **Fig.7.** In the case of anoxic react period of 4.0 hour duration, nitrate (NO_3^-) was reduced to 10.17 mg/L from its peak concentration of 37.96 mg/L. During denitrification phase, the residual soluble COD concentration was found to be more than the stoichiometric organic carbon requirement for effective denitrification meeting all metabolic requirements. The alkalinity value steadily increased during anoxic react phase indicating the presence of active denitrifiers. When the anoxic react period was changed to 3.0 hour, it has been observed that, though nitrate concentration after the aerobic period was found to be maximum, percent removal of nitrate descended from 78 to 62% and 80 to 69% for initial NH_4^+-N concentration of 40 and 90 mg/L respectively. However, in the case of 3 hour aerobic + 5 hour anoxic mode of react period, percent removal of nitrate was marginally improved (76 - 82%).

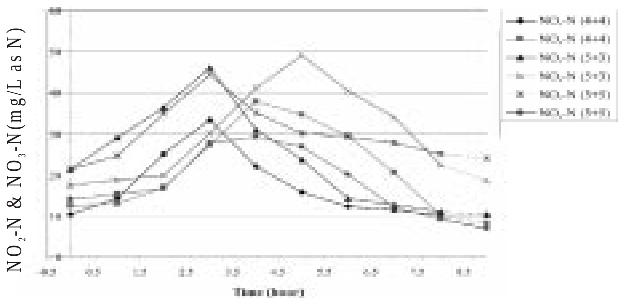

Fig. 6: Nitrite & nitrate concentration profile {Initial SCOD (Tentative)= 1000mg/L; Initial NH_4^+-N (Tentative)= 40mg/L}

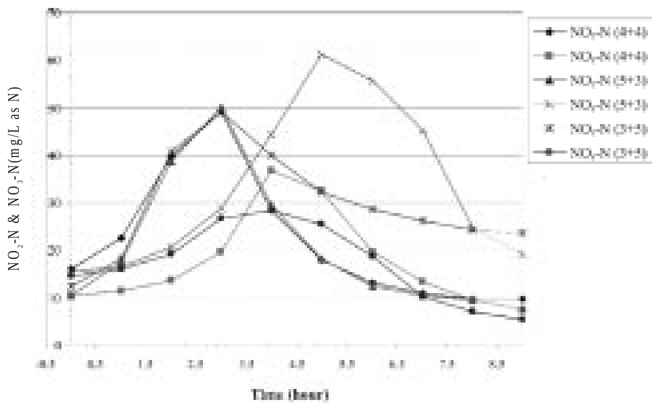

Fig. 7: Nitrite & nitrate concentration profile {Initial SCOD (Tentative)= 1000mg/L; Initial NH_4^+-N (Tentative)= 40mg/L}

Conclusions

The following conclusions are drawn based on the present work on simultaneous removal of organic carbon and nitrogen in a laboratory scale SBR.

- Organic carbon as COD was observed to be stabilized within 65-75 % during aerobic phase of react period corresponding to an initial SCOD level of 1000 ± 100 mg/L. Further SCOD removal was achieved during anoxic phase of react period to have a total SCOD removal at the end of 8.0 hours react period in the tune of 85-92%.
- The SCOD removal during aerobic react period was achieved due to fulfillment of substrate requirement of aerobic microorganisms in the mixed culture. In the anoxic react period, residual SCOD was utilized by the facultative aerobes and denitrifiers.
- Length of aeration period in the react phase of the operation cycle, in the range of 3-5 hours did not have any significant impact on SCOD reduction.
- Longer aeration period (5 hour) has been found to be effective in achieving higher degree of nitrification. However, it affected the percent removal of nitrate due to the prevalence of shorter anoxic period essential for denitrification.
- The pH level in the SBR fell initially during aerobic period due to nitrification and carbon oxidation followed by an increasing trend indicating the existence of denitrifiers. This phenomenon has also been established by the variation of alkalinity level during aerobic and anoxic react period.
- As a whole, it can be concluded that SBR can perform efficiently in achieving nitrification and denitrification sequentially along with oxidation of organic carbon. The combination of 4.0 hour aerobic react period and 4.0 hour anoxic react period has been found to be optimum from the view point of both nitrification and denitrification.

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