Studies on Nutrient removal using Polyurethane Foam (PUF) in Moving Bed Bio reactor (MBBR)

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Abstract - MBBR (Moving Bed Bioreactor) and SBR (Sequential Batch Reactor) were used for nutrient removal from synthetic wastewater consisting of sequence of operation which includes-fill, anaerobic, aerobic, settle and decant phases. The steps in the react cycle are adjusted to provide anaerobic and aerobic phases in certain sequence with variations in duration of time to achieve maximum percent removal of COD, ammonia-nitrogen, nitrate-nitrogen and phosphorous. Polyurethane foam (PUF) was used as media in MBBR. MBBR with Polyurethane foam (PUF) of 10% volume had removal efficiency of 97.74% ,94.16%, 95.48% and 95.23% for COD, Phosphate, Ammonia Nitrogen and Nitrate respectively. MBBR with Polyurethane foam (PUF) of 20% volume had removal efficiency of 75.52%, 97.32% and 97.18% for phosphate, Ammonia Nitrogen and Nitrate respectively. MBBR with Polyurethane foam (PUF) of 30% volume had removal efficiency of 87.02%, 98.2%, 87.02 % for Phosphate, Ammonia Nitrogen and Nitrate respectively.

Key Words: Moving Bed Bioreactor, Sequential Batch Reactor, Polyurethane foam

1. Introduction

The MBBR was developed in Norway at the Norwegian University of Science and Technology in co-operation with a Norwegian company Kaldnes Miljoteknologi (now Anox Kaldnes AS). The first MBBR was installed in 1989. The Moving Bed Biofilm Reactor (MBBR) is a highly effective biological treatment process that was developed on the basis of conventional activated sludge process and bio-filter process. It is a completely mixed and continuously operated Biofilm reactor, where the biomass is grown on small carrier elements that have a little lighter density than water and are kept in movement along with a water stream inside the reactor. This media is designed with a maximum ratio of surface area to weight, and serves as a 'bio-carrier' to which microorganisms attach and form communities. The movement inside a reactor can be caused by aeration in an aerobic reactor and by a mechanical stirrer in an anaerobic or anoxic reactor.

Moreover, as the carrier using in the MBBR is playing a crucial role in system performance, choosing the most efficient carrier could enhance the MBBR performance. Hence, there is need to use an appropriate carrier which is not costly and has a suitable surface for microbial growth.

2. Experimental set up

Reactors were used with media Polyurethane Foam (PUF) with 10%, 20% and 30% volume with total volume of reactor as 5L. The working volume of MBBR were 4L, the influent used was the synthetic wastewater representing the characteristics domestic wastewater. Cow dung was used as seed culture for MBBR.

Before starting the reactor, it was filled with the synthetic wastewater, inoculated with cow dung were operated continuously with aeration and mixing for several days to obtain a dense culture. Aeration was provided by using compressor connected to diffuser stones. At end of each cycle, the mixed liquor suspended solids were allowed to settle for 30 min and 50% of treated wastewater was removed for analysis.

2.1 Influent Wastewater

Nutrient removal from synthetic wastewater was carried out using laboratory Moving bed bioreactor. Synthetic wastewater used throughout the study provided a source of carbon, nitrogen, phosphorous and trace elements required for biomass growth. It was composed of glucose, ammonium chloride, di-potassium hydrogen orthophosphate, magnesium sulphate, sodium hydrogen bi-carbonate and certain concentrations of trace salt materials such as calcium chloride and manganous sulphate. The COD, ammonium nitrogen and phosphorous concentration was 400 mg/L, 32 mg/L and 12.5 mg/L respectively as given in table 2.1

2.2 Operational strategy of MBBR with PUF & PPF

MBBR was operated for one cycle per day with following predetermined operational strategy: Fill, anaerobic, aerobic, settle and decant phases. The operational condition of MBBR is given in the table 2.2

Table 2.2 Operation strategy for MBBR

Volume, Litres	4
Hydraulic Retention time, hrs	48
Number of cycles per day	1
Duration of anaerobic-react phase, hrs	6
Duration of aerobic –react phase, hrs	17

Table 2.1 Composition of the synthetic wastewater

Compounds	Concentration (mg/L)
$C_6H_{12}O_6.H_2O$	400
NH_4Cl_2	125
K_2HPO_4	70.3
$MgSO_4.7H_2O$	50
$MnSO_4$	5
$CaCl_2.2H_20$	3.75
$NaHCO_3$	10

3. Experimental Procedure

1.5 L of the clear supernatant was removed and was filled up to the total volume of 4 L with the fresh synthetic wastewater. Samples of the influent, end of anaerobic phase and end of aerobic phase of MBBR were collected for routine monitoring. Before analysis samples were filtered through 0.45µ filter paper to measure all dissolved chemical parameters. The samples were analyzed for Chemical Oxygen Demand (COD), Ammonia-nitrogen, Nitrate nitrogen and phosphorous in accordance with standard methods. Measurements of pH were carried out by using pH analyzer.

Fig-1: Polyurethane Foam (PUF) media

Table 3 Characteristics of Media

Characteristics	**Polyurethane foam (PUF)**
Shape	Cube
Dimensions (cm)	2.0×2.5×2.5
Void (%)	93
Surface area (cm^2)	24
Pore size (pores/cm)	6±2

4. Results and Discussion

Moving bed Bioreactor system is a variation of the activated sludge process. They differ from activated sludge plant because they combine all of the treatment steps and processes into a single basin or tank, whereas conventional facilities rely on multiple basins. The treatment cycle in an SBR can be adjusted to undergo aerobic, anaerobic and anoxic conditions in order to achieve biological nutrient removal which include nitrification, denitrification and phosphorous as well as organic carbon removal.

To develop EBPR sludge, in addition to the operational conditions of alternating anaerobic and aerobic phases in MBBR systems, the original microbial population in the activated sludge must be important. The microbial concentration responsible for the removal of nitrogen and phosphorous is generally low during startup period. Development of EBPR sludge, a mixed microbial population composed of heterotrophic organisms capable of oxidizing carbonaceous compounds and denitrification; autotrophic nitrifying organisms, anaerobic organisms and phosphate accumulating organisms were used as inoculum culture. These cultures were cultivated in a suitable growth media in the laboratory and were used as inoculum in the form of a mixed culture. [1]

4.1 Performance of MBBR using Polyurethane Foam (PUF) of 10% Volume

The performance of MBBR is typically comparable to the conventional SBR system. The MBBR is an attached cum suspended SBR system wherein microorganisms responsible for the conversion of the organic material or nutrients were found attached to the porous biofilm carriers. Air circulation for the void space was given by diffusers, providing oxygen for the microorganisms growing as an attached film.

At the beginning of cycle, there was a rapid pH reduction signifying increase in phosphorous release rate during anaerobic phase. Then onwards pH increases due to denitrification, the rate of pH decrease was observed to be slower once the phosphorous release process ceased owing to nitrification. There was a change in slope of pH, maximum phosphorous release can be observed in anaerobic conditions. This change in the slope of pH can be used to terminate the anaerobic phase.

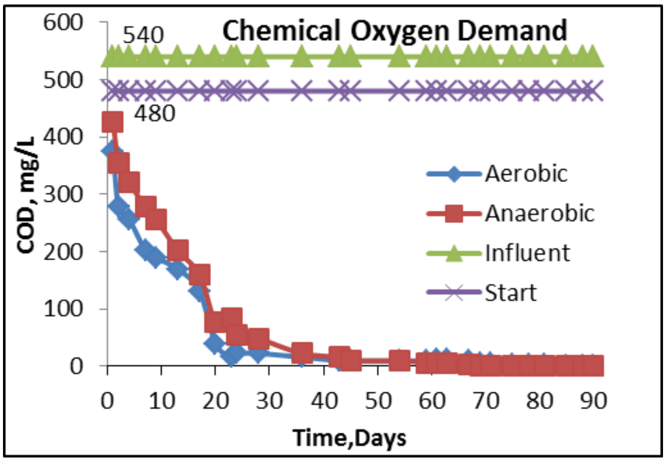
In all cases, the ammonia oxidation rate did not change significantly indicating that the activities of ammonia oxidizers were not influenced significantly by free ammonia or nitrite. The activity of denitrifying microorganisms was also not affected by the nitrite that accumulated as all the nitrite and nitrate produced in the aerobic period were completely removed in the anaerobic period. [2]

The MBBR was operated with the following phases: anaerobic phase (6 h), aerobic phases (17 h), settles, decant and fill phase (1 h). In MBBR, simultaneous nitrification and Denitrification was achieved with a thick biomass. The compound present in the bulk liquid outside the biofilm penetrate the film by diffusion, which leaves the possibility of different conditions and bacterial population in different depths. Zhan et al.,(2006) in his study has reported that oxygen diffused completely into the bottom layer of biofilm with thickness less than 300μm, and the oxygen penetration depth increased with the increasing biofilm thickness. As a consequences, microbial distribution changes with the biofilm thickness due to the competition for the substrate and space in biofilms. In an aerobic biofilm heterotrophs and nitrifiers dominate in the top layer. Therefore, thin biofilms with thickness of 300-400μm are appropriate for simultaneous oxidation and nitrification.

Chart 4.1 and 4.2 shows the variation of COD and phosphorous for the present study period for polyurethane foam using 10% volume. The influent concentration and phosphorous maintained was 540 mg/L and 14.28 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 425.6 mg/L and corresponding phosphorous release observed was 11.02 mg/L. On the day 36, the COD concentration during anaerobic phase was 22.4 mg/L and corresponding phosphorous release observed was 6.61 mg/L and in subsequent the COD concentration during aerobic phase was 16 mg/L and phosphorous release was 5.68 mg/L. In MBBR since the substrate is consumed within the biofilm, the rate of COD uptake was high, and this is because MBBR had another portion of biomass provided by the attached growth.

The COD left in the anaerobic phase was completely consumed in the subsequent aerobic phase. Release of phosphorous was observed in the anaerobic phase and uptake of phosphorous in subsequent aerobic phase. More than 53% uptake of phosphorous was observed after 35 days of reseeding. An increasing trend in the conversion of ammonia nitrogen to nitrite and then to nitrate nitrogen was observed. Further 90-100% nitrification was observed with effluent ammonia nitrogen concentration less than 2mg/l as shown in chart 4.4. In the anaerobic phase, denitrification was there converting nitrate nitrogen to nitrogen gas. Phosphorous concentration decreased rapidly during the aeration phase. The COD reduction started immediately at the onset of the beginning of the cycle, and was further reduced at the end of anaerobic phase since in the attached growth process organic substrate is consumed within the biofilm.

Chart 4.3 and 4.4 shows the variation of ammonia nitrogen and nitrate nitrogen at the end of anaerobic and aerobic phases. On the day 1, ammonia oxidation was 77.06% indicating that the ammonia oxidizing bacteria became dominant, the nitrate that was accumulated in the aerobic phase was oxidized easily. From Chart 4.4 Nitrification was observed when there is a reduction in pH. As a result the required aeration time for nitrification was shorter. The pH started increasing probably due to expelled carbondioxide by air stripping and phosphorous uptake.



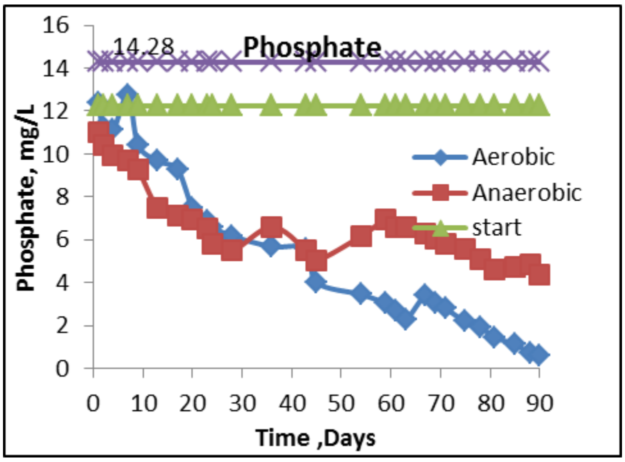
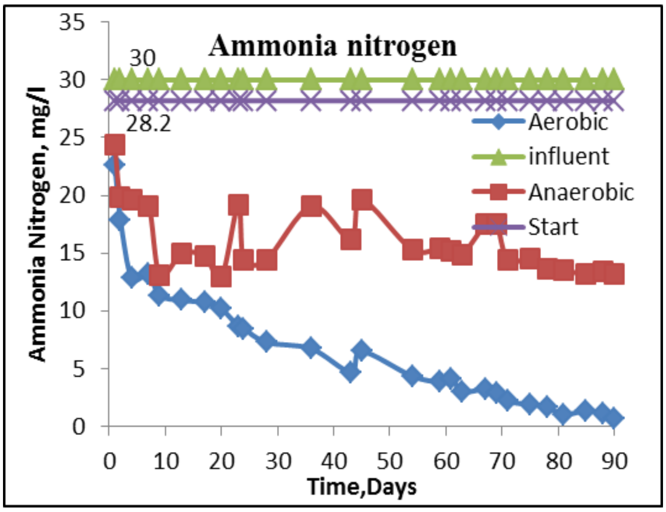


Chart 4.1 **Chart 4.2**

Chart 4.1 Variation of COD in a cycle of MBBR using Polyurethane Foam (PUF) of 10%Volume

Chart 4.2 Variation of phosphate in a cycle of MBBR using Polyurethane Foam (PUF) of 10%Volume



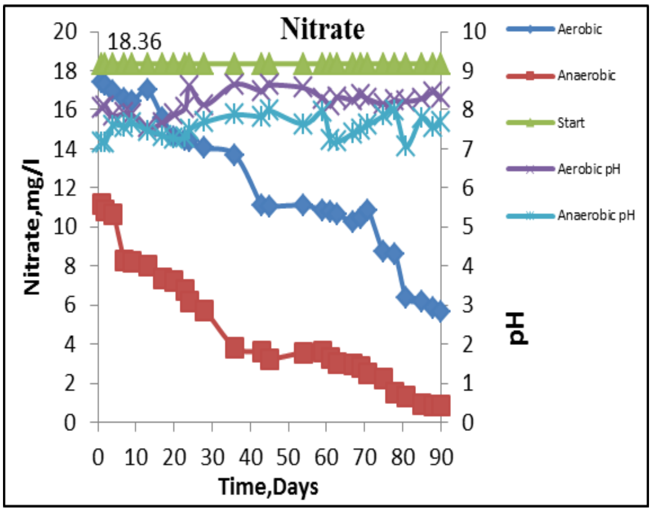


Chart 4.3 **Chart 4.4**

Chart 4.3 Variation of Ammonia Nitrogen in a cycle of MBBR using Polyurethane Foam (PUF) of 10%Volume

Chart 4.4 Variation of Nitrate Nitrogen and pH in a cycle of MBBR using Polyurethane Foam (PUF) of 10%Volume

4.2 Track Studies of MBBR using Polyurethane Foam (PUF) of 10% Volume

During continuous monitoring samples were collected for every 30 mins for both the phases and pH was monitored continuously. Chart 4.5, 4.6 and 4.7 shows variation of COD, pH and ammonia nitrogen. During continuous monitoring different critical points were detected on the pH curve. At the beginning of the cycle, there was a rapid pH reduction. Since pH got reduced, the resuspension of the settled activated sludge resulted in pH decrease, probably due to fermentation of byproducts. Further, the sudden increase in pH indicates denitrification and the point is "nitrate knee", the rate of pH decrease was observed to be slower once the phosphorous release process ceased. This change can be used to terminate the anaerobic phase.

Nitrification was observed when there is a reduction in pH. As a result the required aeration time for nitrification was shorter. The pH started increasing probably due to expelled carbondioxide by air stripping and phosphorous uptake. The reduction in the alkalinity by prevailing nitrification decreases the pH until it reached a minimum. This minimum in the pH profile is called "Ammonium Valley" and correspond to the end of nitrification. After the ammonia reaches to an inflation point before decreasing slightly. This peak is "Nitrate apex" which corresponds to complete nitrification.

The rapid increase in phosphorous was observed during the beginning due to the presence of easily biodegradable substrate which provides a suitable condition for phosphorous release and similar trend was observed until 1.5 hours and was slow during next 0.5h, the rate increased remarkably after 0.5h indicating anaerobic phase. Phosphorous concentration decreased rapidly during aeration phase. The COD concentration reduction started immediately at the onset of the beginning of the cycle, and was further reduced at the end of anaerobic phase due to the presence of easily biodegradable organic substrate. The increase in COD uptake corresponds to the increase in phosphorous release, this is because the PAOs store COD as PHA and use polyphosphate as energy requirements to release phosphorous. Upon initiation of aeration, the COD concentration decreased rapidly, maintaining the same trend until the end of the cycle.

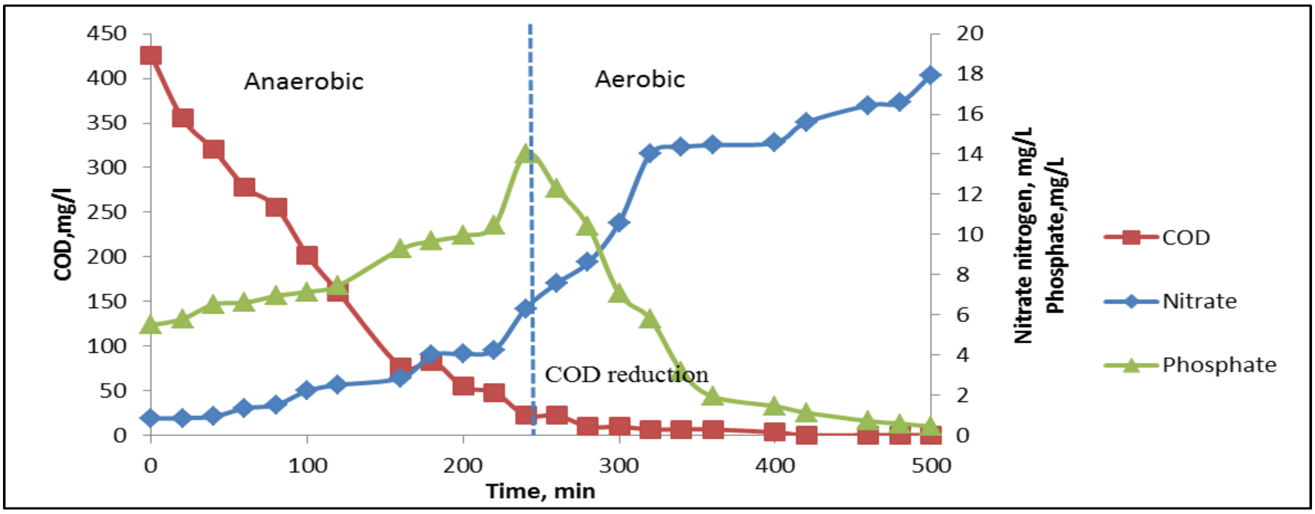


Chart 4.5 Variation of COD, Nitrate and Phosphate in MBBR with Polyurethane of 10% Volume

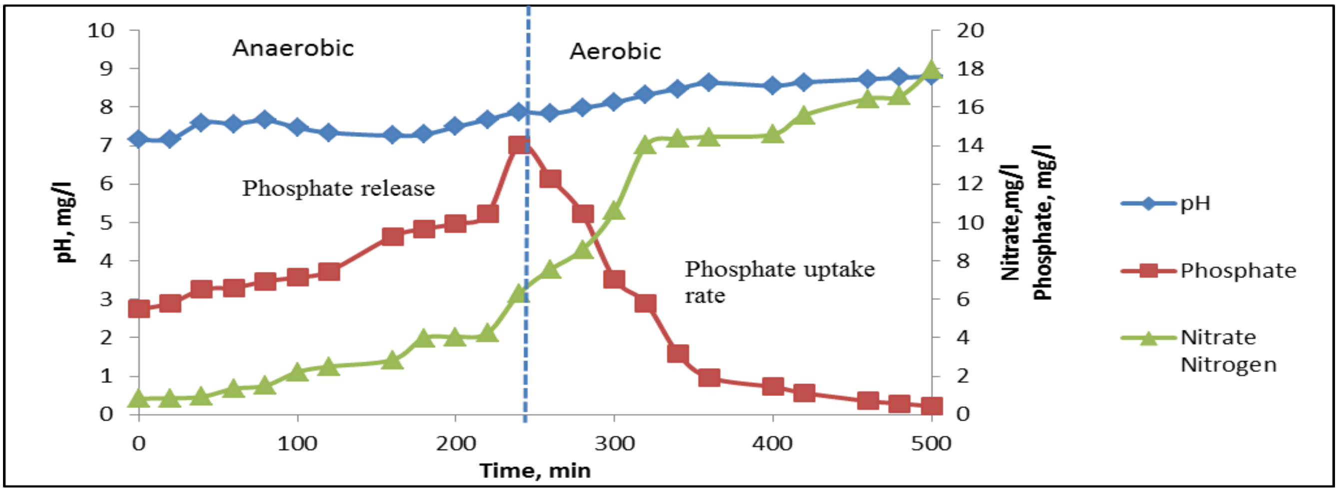


Chart 4.6 Variation of pH and phosphate in MBBR with Polyurethane of 10% Volume

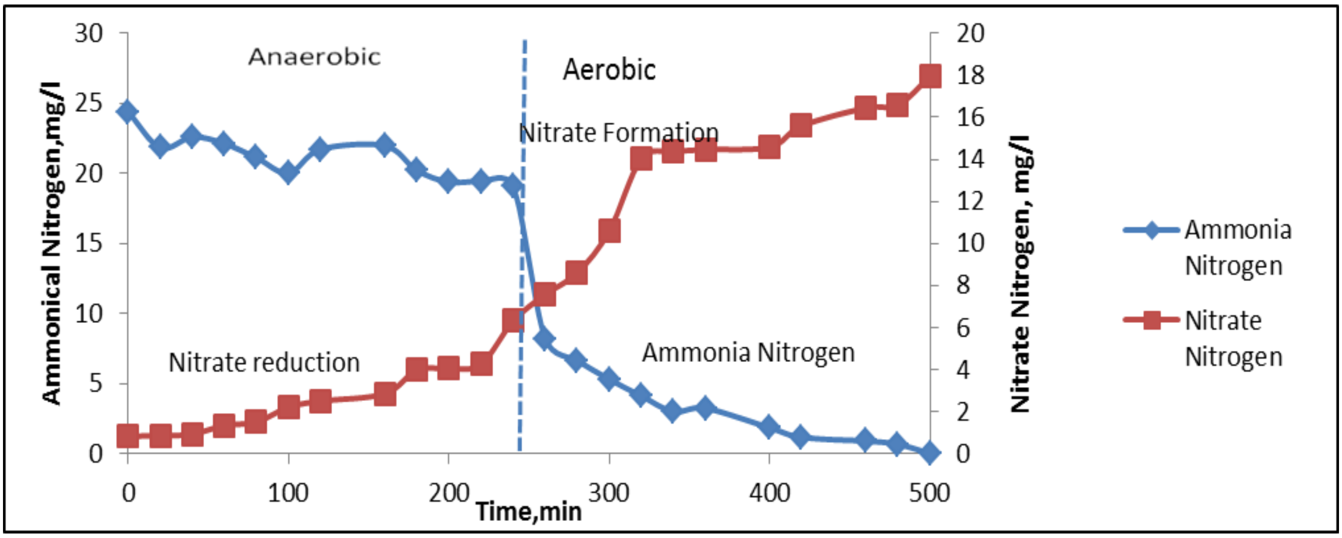


Chart 4.7 Variation of Ammonia Nitrogen and Nitrate in Polyurethane foam 0f 10%

4.3 Performance of MBBR using Polyurethane Foam (PUF) of 10% Volume using Kesare wastewater

Chart 4.8, 4.9, 4.10 and 4.11 shows the variation of COD, phosphorous, Ammonia nitrogen and Nitrate for the entire study period. The influent concentration and phosphorous maintained was 416.6 mg/L and 28.27 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 377.6 mg/L and corresponding phosphorous release observed was 21.23 mg/L. On the day 30, the COD concentration during anaerobic phase was 9.6 mg/L and corresponding phosphorous release observed was 4.420 mg/L and in subsequent the COD concentration during aerobic phase was 0 mg/L and phosphorous release was 0.3040 mg/L. Even though the initial fluctuations were seen in the reactor. Reactor got stabilized after 12 days of start up. COD was effectively removed after 22 days. Denitrification process was effectively observed. Nitrate nitrogen was below 2mg/l within 20 days of period. Hence Polyurethane Foam (PUF) of 10% Volume was slightly efficient in removing nutrients from synthetic and actual wastewater when compared to other volume.

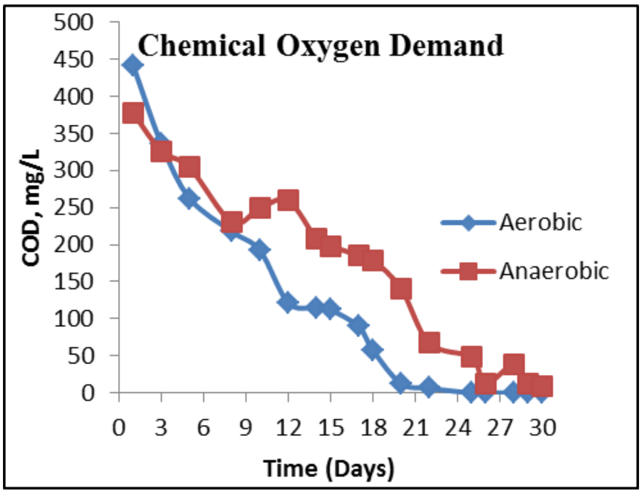


Chart 4.8

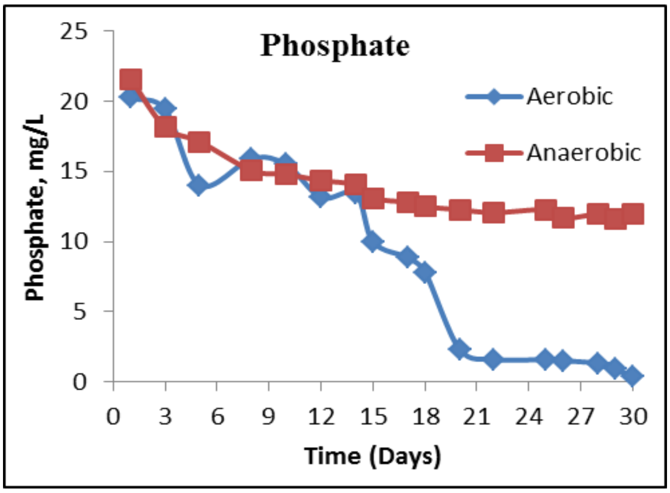


Chart 4.9

Chart 4.8 Variation of COD in polyurethane foam of 10% Volume with Kesare Wastewater

Chart 4.9 Variation of phosphate in polyurethane foam of 10% Volume with Kesare Wastewater

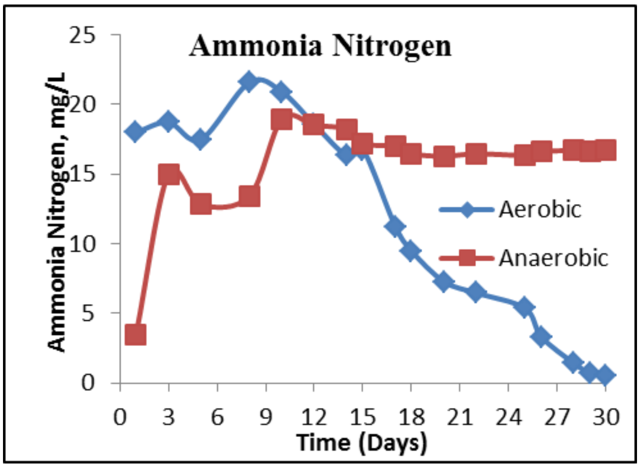


Chart 4.10

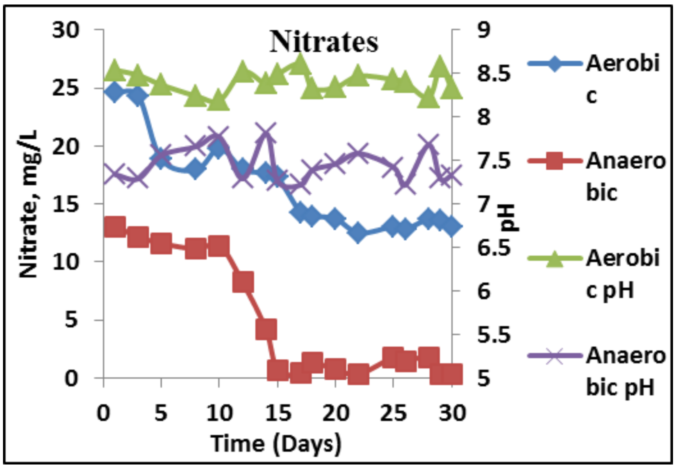


Chart 4.11

Chart 4.10 Variation of Ammonia Nitrogen in polyurethane foam of 10% Volume with Kesare Wastewater

Chart 4.11 Variation of Nitrates in polyurethane foam of 10% Volume with Kesare Wastewater

4.4 MBBR using Polyurethane Foam (PUF) of 20% Volume

Chart 4.12 and 4.13 shows the variation of COD and phosphorous for the entire study period using polyurethane foam of 20% volume. The influent concentration and phosphorous maintained was 540mg/L and 14.28 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 361.6mg/L and corresponding phosphorous release observed was 13.9 mg/L. On the day 36, the COD concentration during anaerobic phase was 48 mg/L and corresponding phosphorous release observed was 8.23 mg/L and in subsequent the COD concentration during aerobic phase was 16 mg/L and phosphorous release was 4.33 mg/L. Phosphorous concentration decreased rapidly during the aeration phase. The COD reduction started immediately at the onset of the beginning of the cycle, and was further reduced at the end of anaerobic phase since in the attached growth process organic substrate is consumed within the biofilm.

Chart 4.14 and 4.15 shows the variation of ammonia nitrogen and nitrate nitrogen at the end of anaerobic and aerobic phases. On the day 1, ammonia oxidation was 66.81% indicating that the ammonia oxidizing bacteria became dominant; the nitrate that was accumulated in the aerobic phase was oxidized easily. Nitrate Nitrogen was reduced below 3mg/L after 60 days.

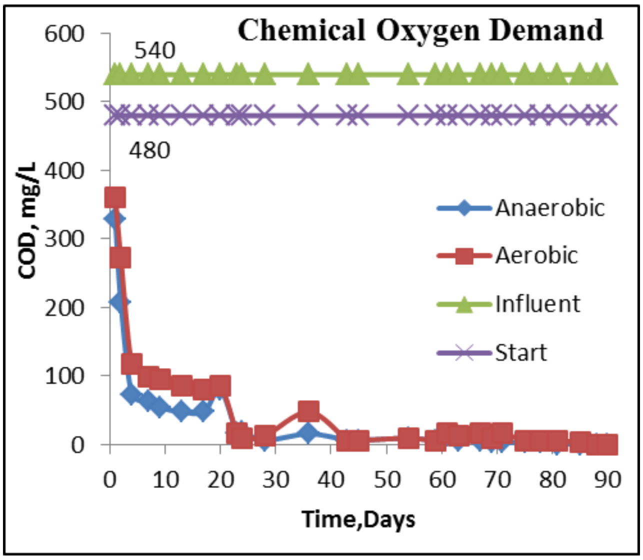


Chart 4.12

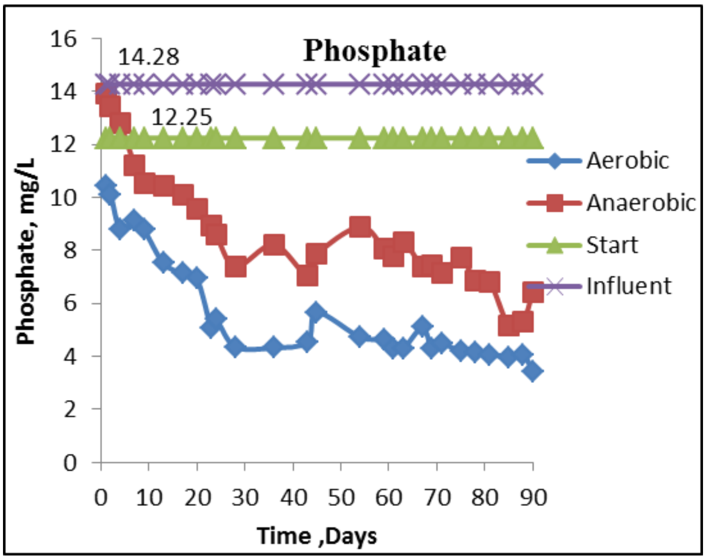


Chart 4.13

Chart 4.12 Variation of COD in a cycle of MBBR using Polyurethane Foam (PUF) of 20%Volume

Chart 4.13 Variation of phosphate in a cycle of MBBR using Polyurethane Foam (PUF) of 20%Volume

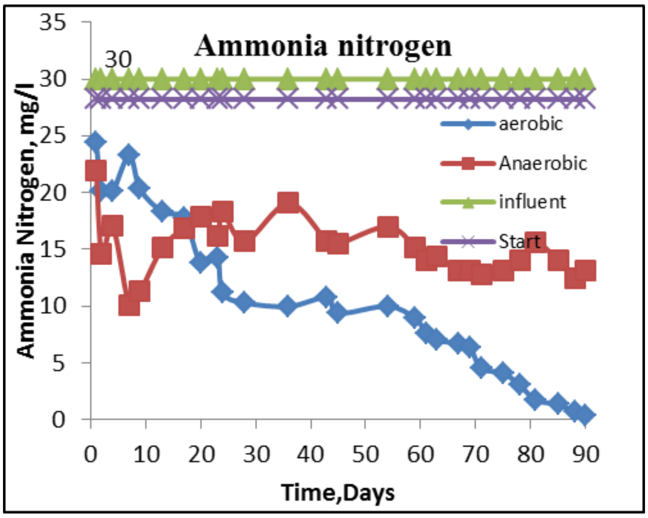


Chart 4.14

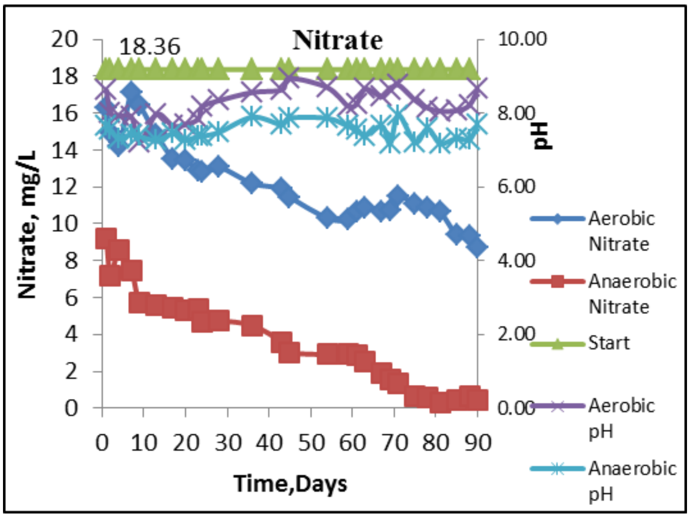


Chart 4.15

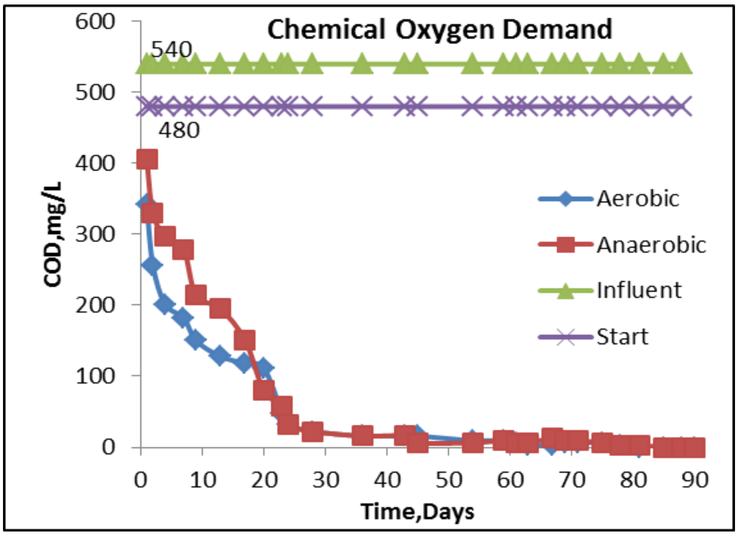
Chart 4.14 Variation of Ammonia Nitrogen in a cycle of MBBR using Polyurethane Foam (PUF) of 20%Volume

Chart 4.15 Variation of Nitrate Nitrogen in a cycle of MBBR using Polyurethane Foam (PUF) of 20%Volume

4.5 MBBR using Polyurethane Foam (PUF) of 30% Volume

Chart 4.16 and 4.17 shows the variation of COD and phosphorous for the entire study period using Polyurethane foam of 30% volume. The influent concentration and phosphorous maintained was 540mg/L and 14.28 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 406.4 mg/L and corresponding phosphorous release observed was 11.72 mg/L. On the day 36, the COD concentration during anaerobic phase was 16 mg/L and corresponding phosphorous release observed was 8.38 mg/L and in subsequent the COD concentration during aerobic phase was 16 mg/L and phosphorous release was 1.07mg/L.

Chart 4.18 and 4.19 shows the variation of ammonia nitrogen and nitrate nitrogen at the end of anaerobic and aerobic phases. On the day 1, ammonia oxidation was 62.28% indicating that the ammonia oxidizing bacteria became dominant, the nitrate that was accumulated in the aerobic phase was oxidized easily.



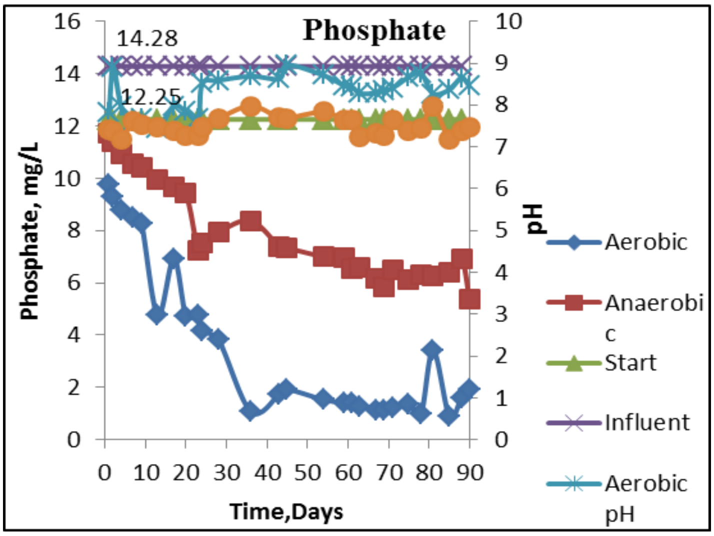
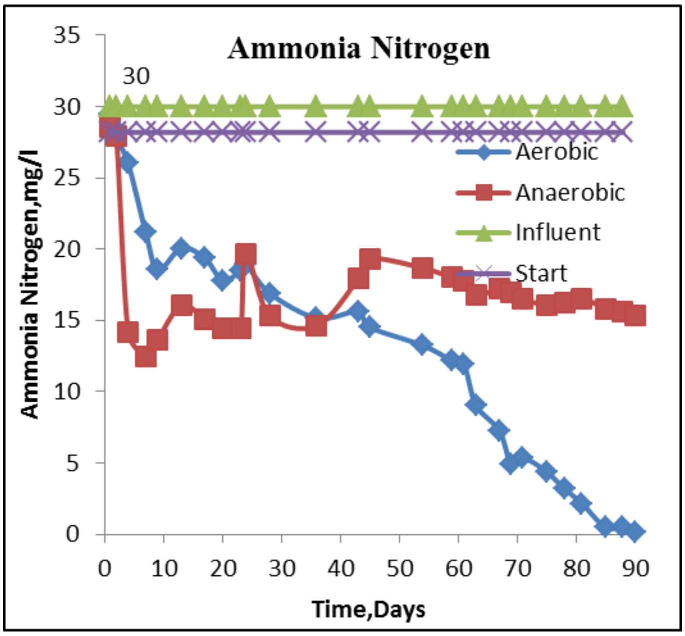


Figure 4.16 **Figure 4.17**

Chart 4.16 Variation of COD in a cycle of MBBR using Polyurethane Foam (PUF) of 30%Volume

Chart 4.17 Variation of Phosphate and pH in a cycle of MBBR using Polyurethane Foam (PUF) of 30%Volume



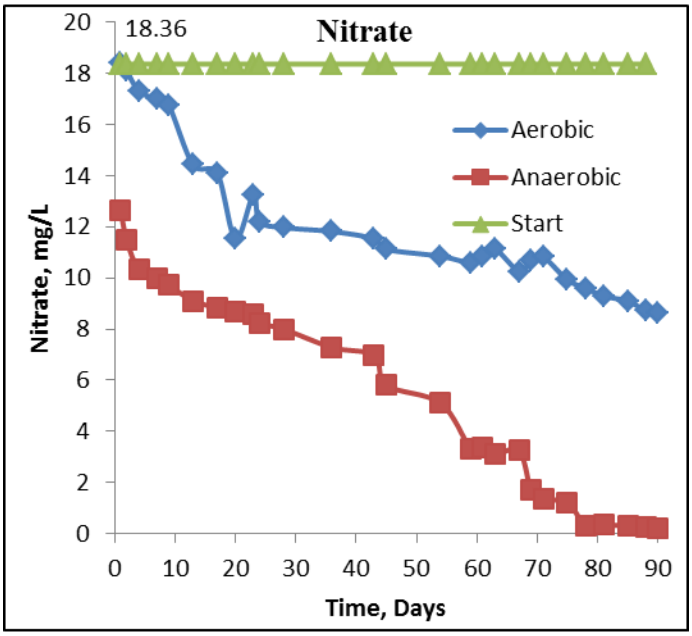


Chart 4.18 **Chart 4.19**

Chart 4.18 Variation of Ammonia Nitrogen in a cycle of MBBR using Polyurethane Foam (PUF) of 30%Volume

Chart 4.19 Variation of Nitrate Nitrogen in a cycle of MBBR using Polyurethane Foam (PUF) of 30%Volume

4.6 Sequential Batch Reactor (SBR)

Chart 4.20 and 4.21 shows the variation of COD and phosphorous for the entire study period using SBR with Kesare wastewater. The influent concentration and phosphorous maintained was 540 mg/L and 14.28 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 438.4 mg/L and corresponding phosphorous release observed was 11.36 mg/L. On the day 36, the COD concentration during anaerobic phase was 118.4 mg/l and corresponding phosphorous release observed was 6.84 mg/L and in subsequent the COD concentration during aerobic phase was 35.2 mg/L and phosphorous release was 4.36 mg/L. Nitrate nitrogen was below 2mg/l within 56 days of period. Chart 4.22 and 4.23 shows variation of variation Ammonia nitrogen and nitrate

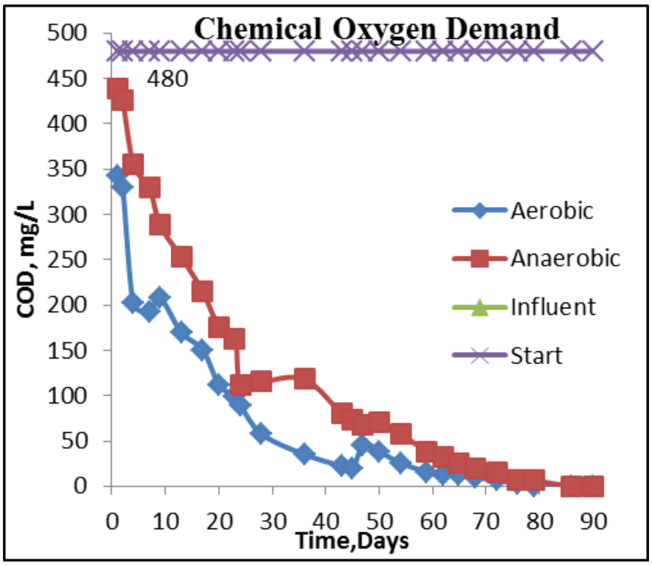


Chart 4.20

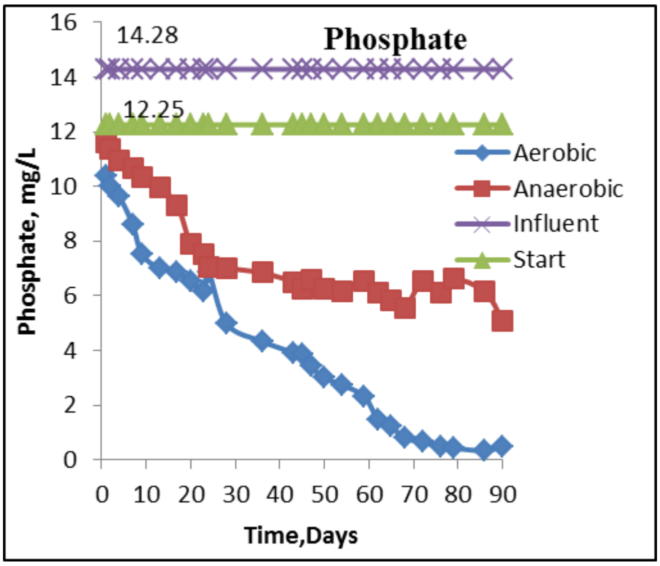


Chart 4.21

Chart 4.20 Variation of COD in a cycle of SBR

Chart 4.21 Variation of Phosphate in a cycle of SBR

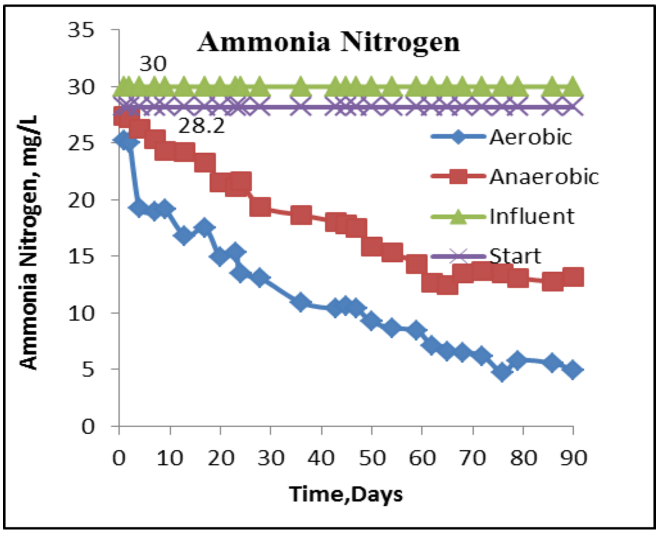


Chart 4.22

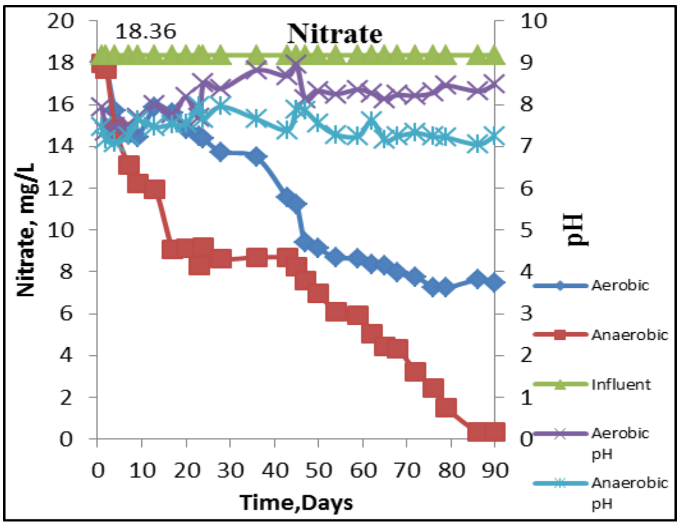


Chart 4.23

Chart 4.22 Variation of Ammonia Nitrogen in a cycle of SBR

Chart 4.23 Variation of Nitrate in a cycle of SBR

4.7 Performance of SBR using Kesare wastewater

Chart 4.24, 4.25, 4.26, 4.27 shows the variation of COD, phosphorous, Ammonia nitrogen and nitrate for the entire study period using SBR with Kesare wastewater . The influent concentration and phosphorous maintained was 416.6 mg/L and 28.27 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 272 mg/L and corresponding phosphorous release observed was 25.51 mg/L. On the day 30, the COD concentration during anaerobic phase was 6.4 mg/L and corresponding phosphorous release observed was 6.9 mg/L and in subsequent the COD concentration during aerobic phase was 3.2 mg/L and phosphorous release was 0.316 mg/L. Even though the initial fluctuations were seen in the reactor. It got stabilized after 12 days of start up. COD was effectively removed after 22 days. Denitrification process was effectively observed. Nitrate nitrogen was below 2mg/L within 18 days of period.

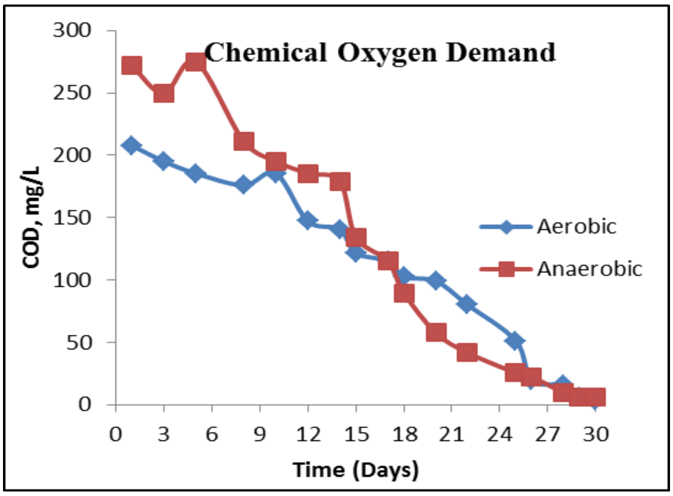


Chart 4.24

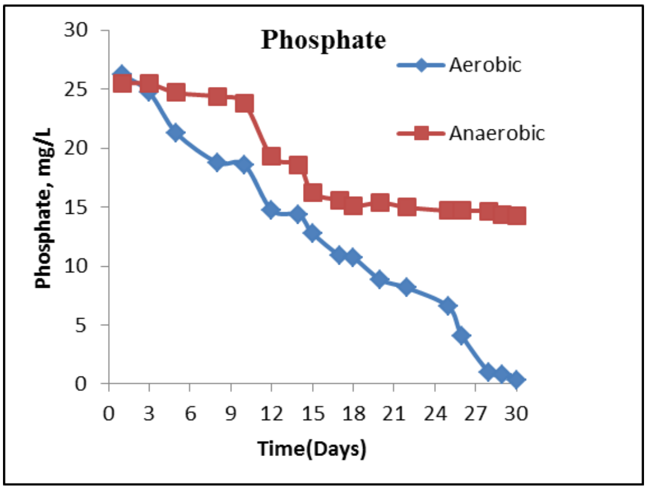
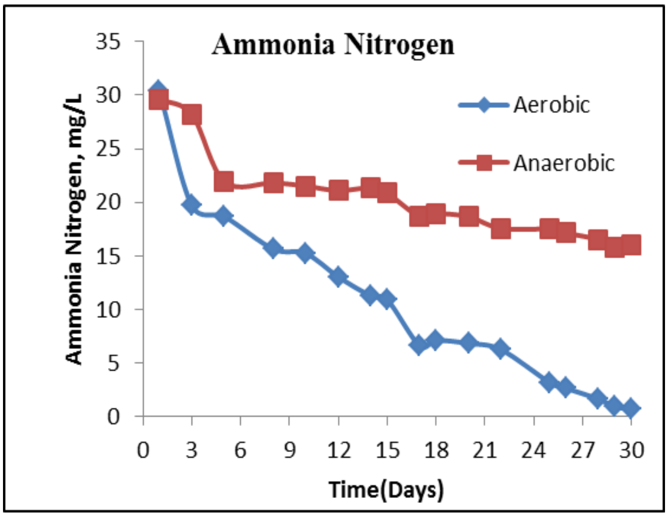


Chart 4.25

Chart 4.24 Variation of COD in a cycle of SBR using Kesare Wastewater

Chart 4.25 Variation of Phosphate in a cycle of SBR using Kesare Wastewater



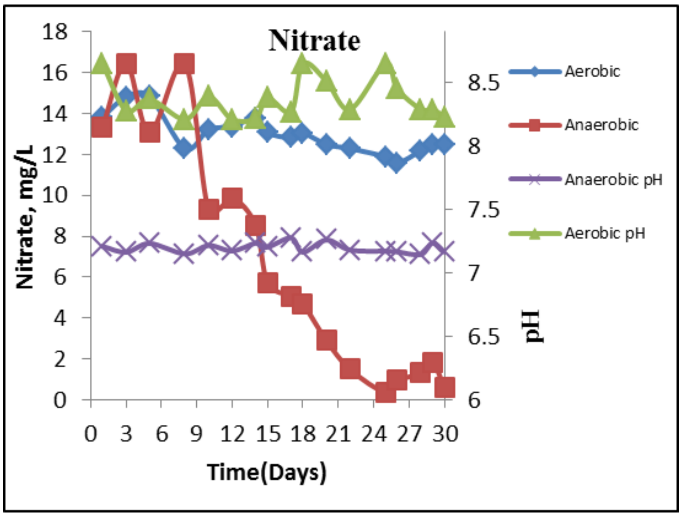


Chart 4.26 **Chart 4.27**

Chart 4.26 Variation of Ammonia Nitrogen in a cycle of SBR

Chart 4.27 Variation of Nitrate in a cycle of SBR

5. Results and Conclusion

Polyurethane foam (PUF) were used in study of varying volume 10%, 20% and 30%. After reseeding in SBR and MBBR, COD uptake was complete with good phosphorous removal efficiency containing less than 9.4 mg/L and 2 mg/L at the end of study period. Nitrification was observed in the aerobic phase and ammonia nitrogen at the end of the cycle was 2mg/L.

MBBR with Polyurethane foam (PUF) of 10% volume showed stable performance for COD with 16mg/L within 23 days. Denitrification process was stable after 30 days with nitrate concentration below 3 mg/L. For the same volume trial run was carried out using Kesare wastewater nitrate concentration was below 1 mg/L after 15 days. COD got removed after 18days of start up. MBBR with Polyurethane foam (PUF) of 20% volume showed stable performance for COD with 6.4mg/L within 23 days. Denitrification process was stable after 45 days with nitrate concentration below 2 mg/L. Ammonia nitrogen was below 1mg/L after 88 days.MBBR with Polyurethane foam (PUF) of 30% volume showed stable performance for COD with 32 mg/L within 30 days. Dentrification process was stable after 48 days with nitrate concentration below 3.32 mg/L. The performance in terms of organic carbon was good in SBR and MBBR. MBBR was efficient for nitrification and denitrification.

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