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Performance Evaluation of Sequencing Batch Reactor for Treatment of Coffee Pulping Wastewater

G. Asha[1*] and B. Manoj Kumar[2]

[1]Department of Civil Engineering, Maharaja Institute of Technology, Mysore, Srirangapatna Taluk, Mandya District, India.
[2]Department of Environmental Engineering, Sri Jayachamarajendra College of Engineering, Mysore, India.

Authors' contributions

This work was carried out in collaboration between two authors GA and BMK. Author BMK wrote the protocol, designed the study, reviewed and edited the final copy. Author GA managed the literature searches, performed the laboratory studies, sample analysis, data interpretation and prepared first draft copy of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The coffee industry uses large amount of water during various stages of coffee production. Coffee processed by wet method generates large volume of high strength wastewater rich in COD and nutrients hence to comply with stringent environmental regulations and for restoration of safe environment, it has become imperative to find less costly and easily adaptable treatment technology. Coffee pulping wastewater characterized as acidic (3.92 – 4.99), high content of suspended and dissolved organic matter makes it amenable to rapid biodegradation. In the present study, Sequencing Batch Reactor (SBR) has been employed has an efficient technology for treating coffee pulping wastewater treatment because of its simple configuration and high efficiency in COD and nutrients removal. The COD in the influent coffee wastewater sample is 8320 to 10400 mg/l, influent phosphorus is 60 to 94 mg/l and influent nitrate nitrogen concentration is 32 to 52 mg/l. The COD concentration remaining in the effluent is 296 mg/l, phosphorus concentration is 3 mg/l and nitrate nitrogen concentration is less than 8 mg/l. With raw wastewater the SBR

**Corresponding author: Email: ashagururaj@yahoo.co.in;*

performance was low and after dilution (1:4) of coffee pulping wastewater the performance of SBR increased in terms of COD, nitrogen and phosphorus removal. This study also showed that there is a need for pre-treatment of coffee pulping wastewater since it contains recalcitrant with high COD concentration and low BOD concentration.

Keywords: Coffee pulping; SBR; anaerobic – aerobic SBR; nutrients.

1. INTRODUCTION

Coffee is of great economic importance to the producing, mostly developing countries, and of considerable social importance to the consuming countries [1]. There are three common species of coffee: *Robusta, Arabica and Liberica*. Only the first two are of commercial importance [2]. In India, coffee pulping is carried out by small and medium sized plantations for whom there are inadequate compulsions to carry out efficient resource recovery and effluent treatment [3,4]. Coffee is processed either by the wet (fermented and washed) processing or dry (natural) processing. In most cases, wet processing is regarded as producing a higher quality product. However, some areas prefer dry processed coffee for its fuller flavor. The coffee industry uses large quantities of water during the various stages of the production process. Consequently, the amount of wastewater generated is high. The Quantity of water used and the volume of wastewater generated in each coffee industry vary from one another depending upon the process adopted since the seasonal nature of the coffee harvest means that coffee pulping mills operate for less than three months a year (November to March). Depending on the processing technology applied, quantities of wastewater is varying. It is estimated that every tonne of coffee produced releases 80 m^3 of wastewater. The process which includes pulping of fruit to remove outer skin and mucilage and cleaning of seeds is quite water intensive and generates about 5 m^3 wastewater per tonne of fresh coffee fruit processed [5].

Water usage for coffee processing by Indian coffee estates varies from 2.25 m^3 to 23 m^3 per tonne of fruit processed [3]. The conventional wastewater treatment technologies being adopted in industrialized nations are quite expensive to build, operate and maintain [6-8]. Moreover, to comply with stringent environmental regulations and for restoration of safe environment, it has become imperative to find less costly and easily adaptable treatment technologies for the wastewater. Sequencing Batch Reactor (SBR) is a promising and efficient technology for wastewater treatment, especially for domestic wastewaters, because of its simple configuration and high efficiency in COD and suspended solids removal. Coffee pulping wastewater is characterized as acidic, high content of suspended and dissolved organic matter rich in sugars and pectins and thus is amenable to rapid biodegradation. The low BOD_5 / COD ratio and the high proportion of volatile solids in relation to total solids indicate the use of biological treatments suitable for these wastewaters [9]. Because the wastewater contained high concentration of COD and nutrients the treatability studies of coffee pulping wastewater was carried out in laboratory scale SBR. The SBR was operated with the five operating phases which include fill, react (anaerobic-aerobic), settle and decant phases.

2. MATERIALS AND METHODOLOGY

2.1 Coffee Wastewater Source

For treatability studies coffee pulping wastewater was collected from pulping units of coffee estates located in Mercara district, Karnataka, India. Coffee grown in this region is pulped using the wet method. In the coffee pulping plant, water is essential as it is used to separate good coffee berries from defective ones, as a method of transporting the coffee berries to the processing machinery, in the elimination of the berry husk from the coffee grains (pulping) and finally in the post fermentation washing process. Furthermore, wet processing diminishes the bitterness and increases the acidity. This process gives rise to one of the smoothest, high quality coffee. Coffee pulping wastewater was collected in polyethylene container and preserved in refrigerator at 4ºC.

Characteristic of wastewater generated from the pulping process contained low pH which varied between 3.92 to 4.99 and high COD between 8320 to 10400 mg/l, BOD concentration of 1600 mg/l, phosphorus concentration was varying between 60 to 94 mg/L, nitrate nitrogen concentration varied between 32 to 52 mg/l, alkalinity was ranging between 85 to 95 mg/l, ammonia nitrogen concentration was in the range of 50 to 84 mg/l, volatile solids of

1550 mg/l, total solids and total dissolved solids concentration was 5000 mg/l and 4500 mg/l respectively. Because the wastewater contained high concentration of COD and nutrients an attempt was made to treat the coffee pulping wastewater in an SBR in order to bring the characteristics to the desired level before it is being disposed. The Sequencing Batch Reactor (SBR) was operated with the five phases including: Fill phase, anaerobic-aerobic phase, settle and decant phases.

2.2 Experimental Set up

SBR was started with total volume of 5 litre, the working volume of SBR was 3 litre. Initially, the influent used was the synthetic wastewater representing the domestic wastewater. In the present study cow dung slurry is used as seed culture. The seed culture used to start biological reactors contain heterotrophs, nitrifiers, denitrifiers [10] and does not contain phosphorus accumulating organisms (PAOs), hence in order to stimulate the growth of PAOs, the SBR was fed with synthetic wastewater containing orthophosphate in the influent. Before starting sequencing batch operation, reactors were filled with the synthetic wastewater, inoculated with cow dung slurry and were operated continuously with aeration and mixing for several days to obtain a dense culture to start with. Aeration was provided by using aquarium pumps connected to two diffuser stones.

2.3 Influent Wastewater

Nutrient removal from synthetic wastewater was carried out using laboratory scale SBR. Synthetic wastewater used provided a source of carbon, nitrogen, phosphorus and trace elements required for biomass growth. It is 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 manganese sulphate. The typical composition of the synthetic domestic wastewater used during the study is presented in Table 1. The COD, ammonia nitrogen and phosphorus concentration in the synthetic wastewater was 400 mg/l, 32 mg/l and 12.5 mg/l respectively with COD: N: P = 32:2.56:1.

2.4 Operational Strategy

SBR was operated with one cycle per day with the following predetermined operational strategy: fill, anaerobic, aerobic, settle and decant phases. In the fill stage wastewater was added into the reactor to mix with the biomass held in the tank. During the react phase the biomass consumes the substrate under controlled conditions i.e. in anaerobic and aerobic. In settle phase, mixing and aeration were stopped and the biomass was allowed to separate from the liquid, resulting in a clarified supernatant. Finally in draw phase supernatant were removed for analysis. The organic loading rate was 8.32 kg COD/m^3-day and hydraulic retention time was 48 hours. The operational strategy of SBR is given in Table 2. Fig. 1 shows the sequence of different phases in an SBR cycle.

Table 1. Composition of the synthetic domestic wastewater

Compounds	Concentration (mg/l)
$C_6H_{12}O_6$. H_2O	400
NH_4Cl	125
K_2HPO_4	70.3
$MgSO_4.7H_2O$	50
$MnSO_4$	5
$CaCl_2.2H_2O$	3.75
$NaHCO_3$	10

Table 2. Operational strategy for SBR

Volume, L	3
Hydraulic Retention Time, h	48
Number of cycles per day	1
Duration of anaerobic phase, h	17
Duration of aerobic phase, h	6
Duration of settle, decant and fill phase	1

2.5 Process Monitoring and Experimental Methodology

All the chemicals used for the analysis were of Analytical Reagent (AR) grade. The samples collected were analyzed for various parameters like COD, ammonia nitrogen, nitrate nitrogen, phosphorus and solids in duplicate. All the analytical procedures followed the standard methods for examination of samples. The samples were filtered through filter paper before analysis. The procedures followed to analyze the parameters of concern were according to the standard methods [11,12]. COD was measured by closed reflux method using HACH apparatus. Ammonia nitrogen was measured by nessler's method by measuring absorbance at 410 nm. In the ultraviolet (UV) screening method for estimating nitrate nitrogen, UV visible recording spectrophotometer was used for measuring the absorbance at 410 nm. Similarly, phosphorus was measured by vanadomolybdo phosphoric acid colorimetric method by measuring absorbance at 470 nm. Volatile solids and Total solids present were measured as per the standard methods. pH was measured using digital pH meter. BOD_5 is measured in terms of Dissolved Oxygen (DO) determination by modified winklers method.

2.6 Anaerobic – Aerobic SBR

The anaerobic-aerobic SBR with a total volume of 5 litre and working volume of 3 litre was operated with one cycle per day. After the development of required biomass for degradation of organic matter in the laboratory scale SBR with synthetic domestic wastewater. The reactor was fed along with coffee pulping wastewater in two phases; in phase-1, raw wastewater was added to SBR while in phase-2 the coffee wastewater was diluted to 1:4 and then it was added to SBR. After aerobic condition the reactor was allowed to settle for 0.5 h. After settling phase, 1.5 litre of the clear supernatant was removed and was filled with fresh feed up to total volume of 3 litre. Samples of the influent, end of anaerobic phase and end of aerobic phase of SBR were collected for analysis.

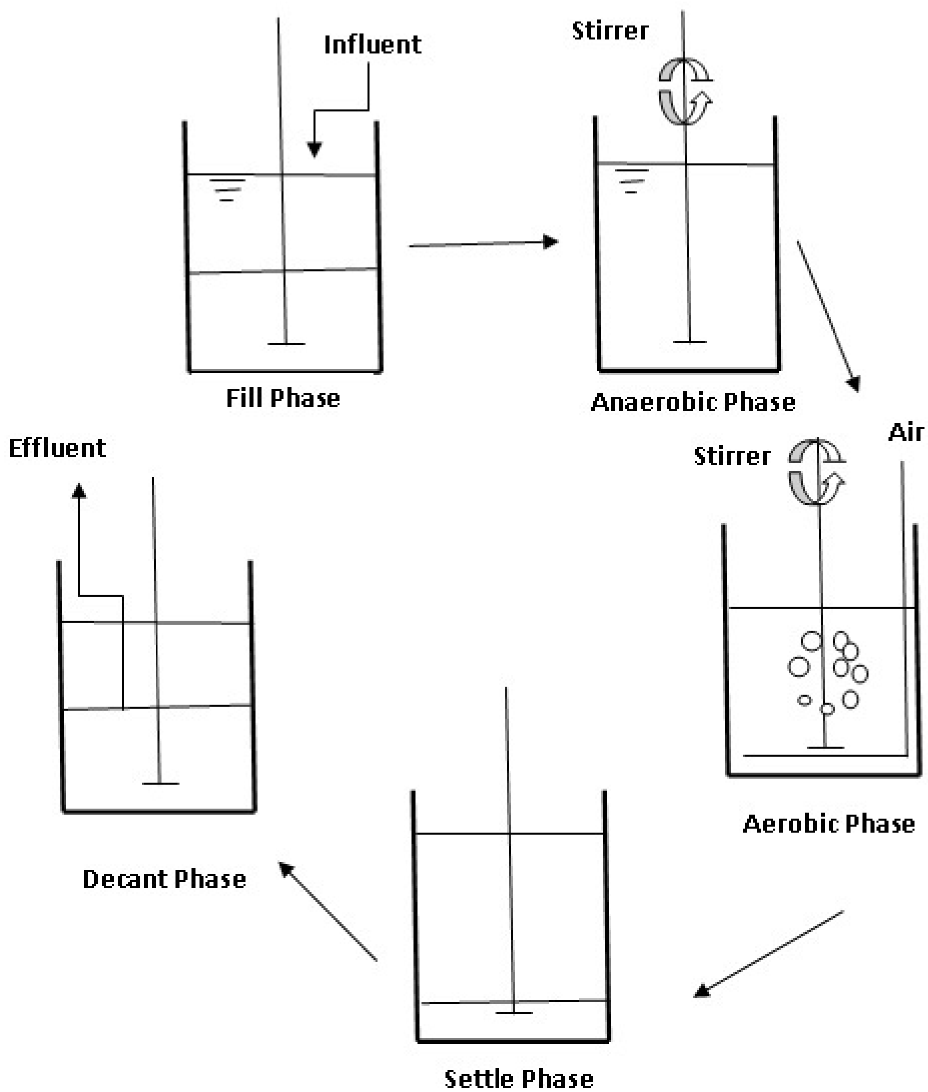

Fig. 1. Sequence of different phases in an SBR cycle

3. RESULTS AND DISCUSSION

This study was conducted to know the feasibility of treating coffee pulping wastewater using SBR. Before conducting the treatability studies, raw coffee pulping wastewater was characterized for the samples collected from coffee estates. The COD:NH_4-N:P ratio of coffee pulping wastewater varied from 208:2:1 to 208:1.8:1 during the entire operation period. Table 3 shows the characteristics of the raw coffee pulping wastewater sample used for the present study.

Table 3. Characteristic of raw coffee pulping wastewater

Parameter	Concentration
pH	3.92-4.99
COD, mg/l	8,320 -10,400
BOD, mg/l	160
Total solids, mg/l	5,000
Total dissolved solids, mg/l	4,500
Volatile solids, mg/l	1,550
Ammonia nitrogen, mg/l	50-84
Nitrate nitrogen, mg/l	32-52
Phosphorous, mg/l	60-94
Chlorides, mg/l	63-72
Sulphates, mg/l	4.4-4.5
Conductivity, µmho/cm	382-390
Alkalinity, mg/l	85-95
Total hardness, mg/l	560-750
Calcium hardness, mg/l	240-350
Magnesium hardness, mg/l	320-700
Aluminum, mg/l	1.2-1.3
Cadmium, mg/l	0.15-0.22
Chromium, mg/l	0.2-0.26
Copper, mg/l	0.15-0.18
Iron, mg/l	6.2-6.86
Manganese, mg/l	0.62-0.67
Nickel, mg/l	0.42-0.45
Lead, mg/l	0.22-0.27
Zinc, mg/l	0.53-0.54

The solids present in the raw coffee pulping wastewater became part of the EBPR sludge developed in the reactor using synthetic wastewater. During the start up of the reactor, the sludge wastage was observed to be more (426 mg/l) in each cycle. This was indicated by low VS/TS ratio value of 0.23 and sludge age was very less in the range of 4-5 days i.e until day 20. After acclimatization period of 21 days, during which VS/TS ratio increased to 0.7, and the sludge age was over 8 days indicating microbial strength. The solids value started increasing after 45 days (from 1418 mg/l to 3459 mg/l) with simultaneous increase in sludge age value of 10 days. Thereafter the sludge age reached a value of 16.14 days. Previous studies have shown that a stable population of microorganisms will exist when the organic loading rate is less (0.3 kg COD / kg TSS d) with improvement in the sludge age over 10 days [13-16].

3.1 Performance of Anaerobic - Aerobic SBR

The results presented and discussed in this section is after startup of SBR using synthetic wastewater. The treatment mode in the SBR is adjusted to undergo anaerobic and aerobic conditions so as to achieve biological nutrient removal, including nitrification, denitrification and phosphorus as well as COD removal. During the initial anaerobic phase, phosphorus is released and carbonaceous material (COD) is stored inside the cell, while in the subsequent aerobic phase, the previously released phosphorus is taken up by microorganisms and the stored organic material is processed. Hence it is concluded by researchers that basic requisite to accomplish simultaneous nitrogen and phosphorus removal, is to provide an alternating anaerobic and aerobic phases in an SBR cycle is required. Because COD, phosphorus and nitrate nitrogen concentration in the wastewater were high an attempt was made in this study to treat the wastewater in SBR of working volume 3 litre. In the SBR it is expected to remove the COD as well as nitrate nitrogen in the anaerobic phase while in the subsequent aerobic phase ammonia nitrogen will be converted to nitrate nitrogen and phosphorus uptake will be there. In a single cycle the SBR is capable of removing COD, ammonia nitrogen, nitrate nitrogen and phosphorus.

Fig. 2 shows the variation of COD for the entire study period. The influent concentration of COD was 10400 mg/l. The COD removal on the first day was less (phase-1). Slow linear COD uptake in anaerobic phase was observed, around 28% and in the subsequent aerobic phase it was around 39%, these findings are in line with trends observed by [17]. Up to day 51, the raw coffee pulping wastewater concentration was varying between 9460 to 10400 mg/l and at the end of the anaerobic phase the COD concentration was varying between 3300 to 5325 mg/l. While in the subsequent end of the aerobic phase the COD concentration was varying between 2280 to 4500 mg/l. During these days the COD removal observed was in the range of 28% to 47%. From day 53 to 63 the raw coffee pulping wastewater concentration was in the range of 8320 to 9400 mg/l and the COD concentration at the end of anaerobic phase was varying between 1750 to 3200 mg/l. At the end of the aerobic phase the COD concentration was varying in the range of 2300 to 2560 mg/l. During these days the COD removal observed was in the range of 40 to 44%.

Because the effluent COD concentration was high it was decided to reduce the influent COD concentration by dilution with tap water (phase - 2). From the Fig. 2, it can be observed that on day 72, the removal efficiency decreased as the influent COD increased, probably because the limited reaction time of 6 h that was kept fixed and may be due to dissolved oxygen, being a limiting factor, resulting in lower removal efficiencies at the higher COD loading conditions [18]. The dilution done to raw coffee pulping wastewater was 1:4 (250 ml in 1000 ml). By this the coffee pulping wastewater concentration reduced to 3500 mg/l. The end anaerobic COD concentration was 1750 mg/l and the effluent COD concentration was 550 mg/l. The percent COD removal in the anaerobic phase was 50%, while the total removal in a cycle was 81 %. As it can be seen from the Fig. 1, after 94 days, the COD values at the end anaerobic was 763 corresponding to 66%, while in the effluent, COD concentration was less than 296 mg/l corresponding to 87% removal. At this stage the sludge age reached a value of 16.14 days indicating the presence of microbial populations to degrade the organic pollutants. Later the same trend was observed until day 126 and thereafter a declining in the removal was observed, the possible reason may be due to the loss of biomass which may be attributed to the fact that sludge age is decreased to less than 6 days. This is in accordance with [13], revealing that the COD removal rate increases with the increase in the sludge age.

Fig. 3 shows the phosphorus variation in the SBR cycle for the study period. The influent concentration of phosphorus was varying between 80 to 94 mg/l. The phosphorus removal during initial few days was less because the biomass was not acclimatized to higher influent phosphorus concentration (phase-1). The phosphorus release in the anaerobic phase was around 60%, because in anaerobic condition the microorganisms take up carbon source and accumulate PHB, and release phosphorus [19] and in the subsequent aerobic phase the phosphorus uptake observed was 3% i.e. the PAOs take phosphorus excessively to store it in the form of poly-p [14]. Previous studies have proved that phosphorus can be removed by repetitive operation of anaerobic and aerobic steps. Up to day 51 (Fig. 3) the raw coffee pulping wastewater phosphorus concentration was 80 to 94 mg/l to 20% but there was fluctuation in the phosphorus removal. From day 53 to 63 (Fig. 3) phosphorus in the raw coffee pulping wastewater concentration was in the range of 75 to 80 mg/l and the phosphorus concentration at the end of anaerobic phase was varying between 66 to 81 mg/l. At the end of the aerobic phase the phosphorus concentration was varying in the range of 50 to 59 mg/l. Since the uptake of phosphorus in the aerobic phase was less, it was decided to reduce the influent phosphorus concentration by dilution (phase-2). The dilution done to raw coffee pulping wastewater was 1: 4 (250 ml in 1000 ml). By this the phosphorus concentration reduced to a range of 13 to 20 mg/l. The end anaerobic phosphorus concentration was in the range of 12 to 36 mg/l and the effluent phosphorus concentration was less than 9 mg/l. It is clear from the Figs. 2 and 3 that the decrease in phosphorus concentration is associated with the increase in the COD uptake by the microorganisms. These observations are in line with the findings of [20]. The percent phosphorus release in the anaerobic phase was 67%. The effluent phosphorus concentration was less than 3 mg/l corresponding to 80% from day 126 onwards. It can be seen from Fig.3, that there was phosphorus uptake with simultaneous denitrification (Fig. 4), these findings are consistent with [21].

Nitrate nitrogen concentration variation during the study period is shown in Fig. 4. The influent concentration of nitrate nitrogen was varying between 41 to 50 mg/l up to day 51. The nitrate nitrogen concentration at the start of anaerobic phase consisted of influent concentration plus nitrate nitrogen formed in aerobic phase of previous cycle due to nitrification. The nitrate nitrogen removal in the anaerobic phase on initial few days was less because the microbial concentration responsible for the removal of nitrogen and phosphorus is generally slow in the start-up period [14] (phase-1). The denitrification in the anaerobic phase observed was around 59 %. Up to day 51 at the end of the anaerobic phase the nitrate nitrogen concentration was varying between 11 to 22 mg/l. During these days the nitrate nitrogen removal observed was in the range of 12% to 38%. This may be attributed for low uptake of COD by denitrifying organisms in the anaerobic phase and the low biomass concentration. From day 53 to 63 the raw coffee pulping wastewater concentration was in the range of 20 to 40 mg/l. Some amount of denitrification was observed during this period, the nitrate nitrogen concentration at the end of anaerobic phase was varying between 8 to 10 mg/l. At the end of the aerobic phase the nitrate nitrogen concentration was varying in the range of 32 to 52 mg/l and this increase in nitrate nitrogen concentration is due to nitrification taking place in the aerobic phase. Because the effluent nitrate nitrogen concentration was high the influent nitrate nitrogen concentration was reduced by dilution during phase-2 studies (250 ml in 1000 ml). By this, the wastewater nitrate nitrogen concentration reduced to a range of 15 to 27 mg/l. At the end of anaerobic phase the nitrate nitrogen concentration was in the range of 8 to 10 mg/l and the effluent nitrate nitrogen concentration was in the range of 3 to 10 mg/l. As it can be seen from the Fig. 4, after 94 days, the effluent nitrate nitrogen values were less than 8 mg/l. As reported by [22] the highest nutrient removal efficiency was obtained for the SBR operation with an anaerobic to aerobic time ratio of 2.0. From the day of dilution onwards the nitrate nitrogen removal efficiency was observed to be constant.

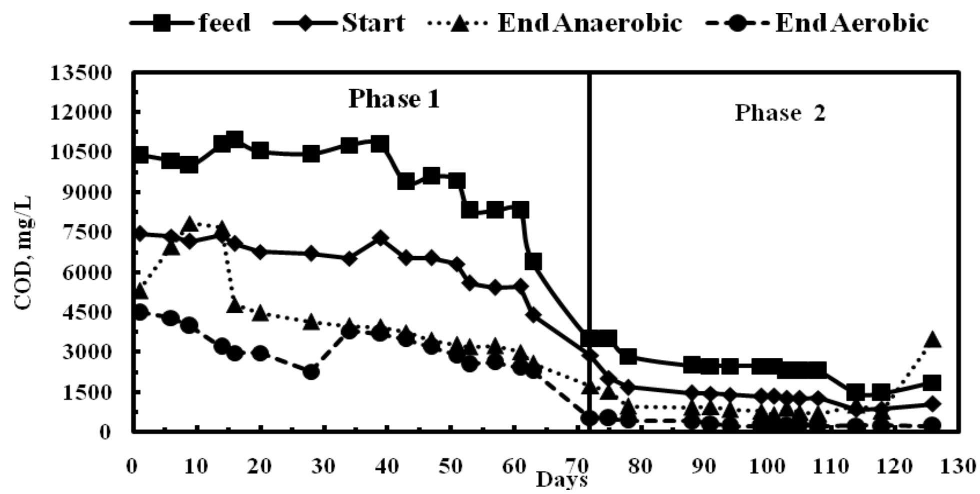

Fig. 2. Variation of COD during the study period

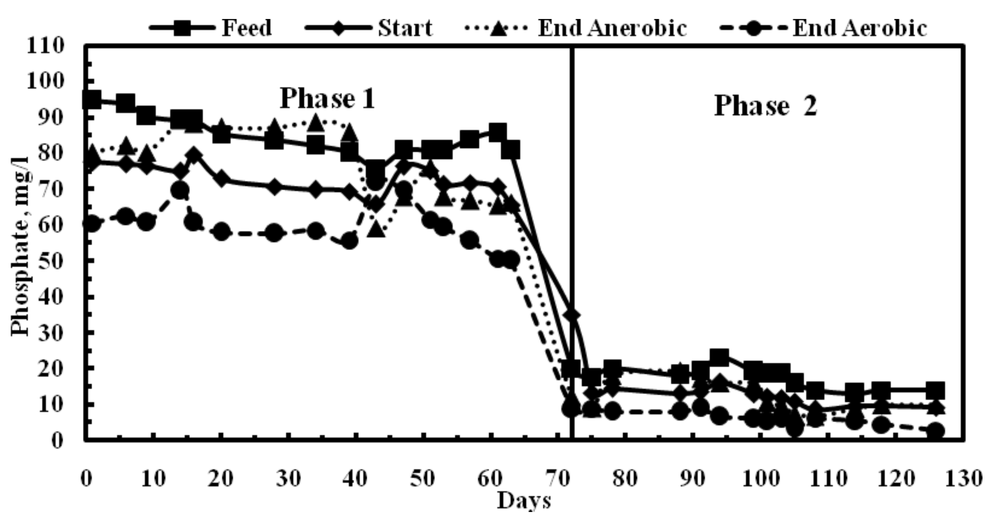

Fig. 3. Profiles of phosphorus during study period

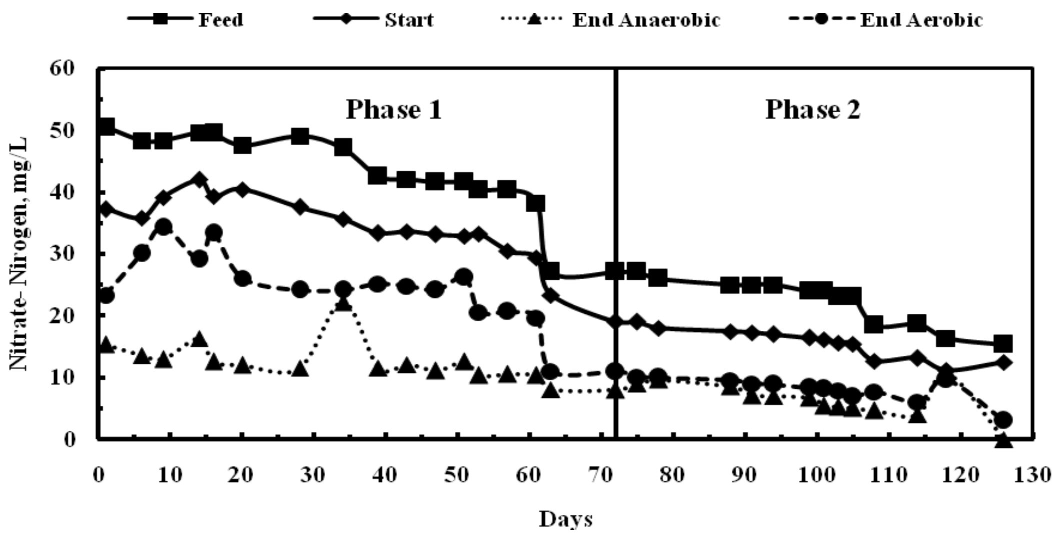

Fig. 4. Variation of nitrate nitrogen during study period

4. CONCLUSION

The coffee pulping wastewater contained high concentration of COD and nutrients. In this study an attempt has been made to treat the same in an SBR in order to bring the characteristics to the desired level before it is being disposed. From the study, following conclusions were drawn.

1. Studies done in an anaerobic-aerobic SBR, operated for a period of 126 days reveal up to day 51, the COD removal was less i.e. Uptake in anaerobic phase was less around 28% and in the subsequent aerobic phase it was reduced by 39%.
2. The results of the study indicated that the performance of the anaerobic-aerobic SBR was fluctuating in nature initially and hence the removal efficiency was not consistent. This is possibly due to presence of slow growing nitrifying and phosphate accumulating organisms, which flush out very rapidly leading to lower sludge age. Another, possibility may be that due to the complex organic compounds present in the coffee pulping wastewater which are not able to be degraded by microorganisms.
3. The low performance of SBR was observed when the SBR was fed with raw wastewater with BOD_5 to COD ratio ranging from 0.015 to 0.019, which is detrimental to the performance of bioreactor.
4. When the wastewater was diluted to 1: 4 ratio, there was increase in the performance of SBR with the effluent COD less than 300 mg/l corresponding to nearly 92% removal efficiency.
5. After dilution, the nitrate nitrogen concentration at the end of anaerobic phase was less than 10 mg/L and at the end of aerobic phase the phosphorus concentration was less than 3 mg/L.
6. The study results showed that the biological treatment using anaerobic-aerobic SBR system reduces the concentration of coffee pulping wastewater, but the time taken to stabilize the system is more and due to complex organic compounds present in wastewater (high COD and low BOD) which are not degraded by microorganisms, hence pretreatment is in demand to destroy the recalcitrant substances.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Chapagain AK, Hoekstra AY. The water footprint of coffee and tea consumption in the Netherlands. J. of Eco. Econ. 2007;64: 109-118.
2. Chanakya HN, De Alwis AAP. Environmental issues and management in primary coffee processing. J. of Pro. Saf. and Environ. Prot. 2004;82:291-300.
3. Chanakya HN, Deepa GB, Vinutha D, Modak JM. Mulitfeed biogas reactor for

coffee wastewater and biomass wastes-performance highly fluctuating operating conditions; 2004.
4. Murthy KVN, D'Sa A, Kapur G. An effluent treatment-cum-electricity generation option at coffee estates: Is it financially feasible? Draft version. Int. Ene. Initiative; 2004. Bangalore.
5. Lata K, Kansal A, Balakrishnan M, Rajeshwari KV, Kishore VVN. Assessment of biomethanation potential of selected industrial organic effluents in India. Resource Con. and Recy. 2002;35:147–161.
6. Piet NL, Piet MV, Lode S, Willy HV. Direct treatment of domestic wastewater by percolation over peat, bark and wood chip. Wat. Res. 1994;28:17-26.
7. Mazumder SCB, Kumar K. Removal / recovery of aceticacid from wastewater by adsorption on bagasse and coconut jute carbon. Indian J. of Environ. Health. 1999; 41:170-175.
8. Mazumder D, Roy B. Low cost options for treatment and reuse of municipal wastewater. Indian J. of Environ. Prot. 2000;20:529-532.
9. Matos AT, Lo Monaco PA, Pinto AB, Fia R, Fukunaga DC. Pollutant potential of wastewater of the coffee fruits processing. Federal University of Viçosa, Department of Agricultural Engineering, Viçosa-MG; 2001. Brazil.
10. Kargi F, Uygur A. Biological nutrient removal in sequencing batch reactor with different number of steps. Clean Techn. and Environ. Policy. 2003;6(1):61-65.
11. American Public Health Association (APHA), American Water Works Association and Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 15th Edition, Washington DC, USA; 1980.
12. American Public Health Association (APHA), American Water Works Association and Water Pollution Control Federation, Standard Methods for the examination of Water and Wastewater, 20th Edition, Washington DC, USA; 1988.
13. Martinez AB, Barcelo OG, Martinez SG. Nutrient removal and sludge age in a sequencing batch reactor. Bio. Eng. 2000; 23:41-45.
14. Chang HM, Moon RK, Park BG, Lim SJ, Choi DW, Lee WG, Song SL, Ahn YH. Simulation of sequential batch reactor (SBR) operation for simultaneous removal of nitrogen and phosphorus. Bioprocess Eng. 2000;23:51-52.
15. Al-Rekabi WS, Qiang H, Qiang WW. Review on sequencing batch reactors. J. of Nut. 2007;6:11-19.
16. Jungles MK, Campos JL, Costa RHR. Sequencing batch reactor operation for treating wastewater with aerobic granular sludge. Brazilian J. of Chem. Eng. 2014; 31(1):27-33.
17. Goncalves IC, Penha S, Matos M, Santos AR, Franco F, Pinheiro HM. Evaluation of an integrated anaerobic/aerobic SBR system for the treatment of wool dyeing effluents. Biodegr. 2005;16:81–89.
18. Laughlin DK, Edwards FG, Egemen E, Nirmalakhandan N. SBR treatment of high COD effluent from bottling plant. J. of Environ. Eng.1999;285-291.
19. Nicholls HA, Osborn DW. Bacterial stress: Prerequisite for biological removal of phosphorus. J. of Wat. Poll. Con. Federation. 1979;51(3):557-569.
20. Ahn CH, Park JK, Kim KS. Microbial adaptability to organic loading changes in an enhanced biological phosphorus removal process, J. of Environ. Eng. 2006; 132:909-917.
21. Linjiang Y, Wei H, Lei W, Yongzhe Y, Zhiying. Simultaneous denitrifying phosphorus accumulation in a sequencing batch reactor. Front. Environ. Sci. Eng. China. 2007;1(1):23-27.
22. Freitas F, Temudo M, Reis MAM. Microbial population response to change of the operating conditions in a dynamic nutrient-removal sequencing batch reactor. Bio. Biosyst Eng. 2005;28:199-209.

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