Performance of upflow anoxic bioreactor for wastewater treatment

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ABSTRACT: Laboratory scale studies were conducted in an up-flow anoxic bioreactor (UFAB) using synthetic fertilizer wastewater for ascertaining the denitrification efficiency. The performance of the reactor was compared using ethanol and topioca starch as the carbon source. The initial NO_3-N concentrations (50-250 mg/L) and hydraulic retention time (HRT, 12-24 h) were varied to evaluate the COD and NO_3-N removal. The results from this study shows that ethanol gave very good denitrification efficiency (78-98%) compared to topioca starch (68-96%).

Key words: *Denitrification, topioca wastewater, up-flow anoxic bioreactor, HRT*

INTRODUCTION

Nitrogen is one of the principal nutrients of concern in treated wastewater discharges. The increased use of nitrate (NO_3-N) fertilizers and discharge of partially treated industrial wastes to rivers leads to exceedingly high NO_3-N levels in rivers and groundwater. High levels of NO_3-N are a major contributing factor in the problem of eutrophication of water bodies. The drinking water standard set by the European Economic Community (EEC) for NO_3-N is 50 mg/L, while 44 mg/L was set by the U.S. Environmental Protection Agency (USEPA). Nitrogen removal can be effectively accomplished by biological processes involving the nitrification and denitrification steps. Abu-Ghararah, 1996 investigated the influence of type of carbon source and NO_3-N loading on the denitrification process of NO_3-N contaminated drinking water in an anoxic static bed column. NO_3-N loading in the range 0.240 -1.30 Kg NO_3-N/m^3.day was investigated. The results of the study have shown that the system should be operated at a maximum NO_3-N loading of 0.45 Kg NO_3-N/m^3.day to treat waters having a NO_3-N concentration of 500 mg/l to the allowable effluent NO_3-N and NO_2-N concentrations. Bilanovic, *et al.,* 1999 studied de-nitrification under high nitrite concentration in fed-batch mode. Methanol, sodium acetate and effluent from anaerobic digesters were compared as carbon sources. A maximum nitrite removal rate was found to be 0.486 g NO_3-N/ g VSS.day. Nitrite accumulated initially but its concentration decreased with time and reached zero when acetate or other effluents were used as carbon source. Up-flow anoxic bioreactors (UFAB) are biological systems that have proved to achieve high denitrification rates under controlled operating conditions. The main objective of the present study is to evaluate the COD and NO_3-N removal efficiency using HRT and influent NO_3-N concentration as the independent variables.

MATERIALS AND METHODS

Experimental

The laboratory scale anoxic up-flow bioreactor used in this study is shown in Fig. 1. It was made of acrylic cylinder (100 mm ID*1100 mm height) having 8 lit capacity. Polyurethane foams in the form of 30 mm cubes were used as packing material which serves as supporting media for the micro-organisms in the reactor. The packed bed height was 64.5 cm. The reactor had perforated plates to hold the packing firmly. The perforations in the plate also ensured uniform distribution of influent wastewater through the reactor bed. The influent synthetic wastewater moved upward through the packed bed with different velocities based on hydraulic retention time (HRT). Along the reactor length, two taps were provided at heights of 23 cm and

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44.5 cm from the base which served as sampling ports. The final effluent was collected after the substrate had moved through the complete packed height of 64.5 cm. The CO_2 and CH_4 gases were collected through outlet tap in tubes by the downward displacement of water. The substrate was fed into the reactor continuously by a variable speed peristaltic pump.

Media composition

The synthetic fertilizer wastewater compositions as shown in Tables 1 and 2 were used in this study, Menoud, *et al.,* 1999. Tapioca starch slurry and ethanol were used as carbon sources.

Table 1: Synthetic fertilizer wastewater composition

Sl.No	Constituent	Composition
1	Glucose	1000 mg/L
2	NH_4NO_3	80 mg/L
3	KH_2PO_4	30 mg/L
4	K_2HPO_4	15 mg/L
5	Nutrient solution	1 mL

Table 2: Composition of nutrient solution

Sl.No	Chemical	Composition (g/L)
1	$MgSO_4.7H_2O$	90
2	$CaCl_2.2H_2O$	6
3	$FeCl_3.6H_2O$	1.5
4	$MnCl_2.4H_2O$	6.5
5	$ZnSO_4.7H_2O$	1.7
6	$CuCl_2.2H_2O$	0.1
7	$CoCl_2.6H_2O$	1.9
8	$NiSO_4.6H_2O$	6.5
9	H_3BO_3	0.1
10	$Na_2MoO_4.2H_2O$	0.6
11	Yeast extract	1

Start up and acclimatization

Cow dung slurry of 8 L was fed regularly into the reactor with 24 h HRT for a period of about 4 weeks. Additionally, 500 mL of a mixture of sludge from a previously operated bioreactor and domestic sewage in equal proportion were also seeded for fast biofilm development. The pH of the cow dung slurry and sludge mixture was adjusted to 7.5 using sodium bicarbonate. After 4 weeks the cow dung slurry mixture was replaced by synthetic fertilizer wastewater at a rate of 10 % by volume in every 48 h till the cow dung slurry mixture was reduced to zero volume. The acclimatization step took 33 days for obtaining steady state removal of COD (40%) and biofilm development.
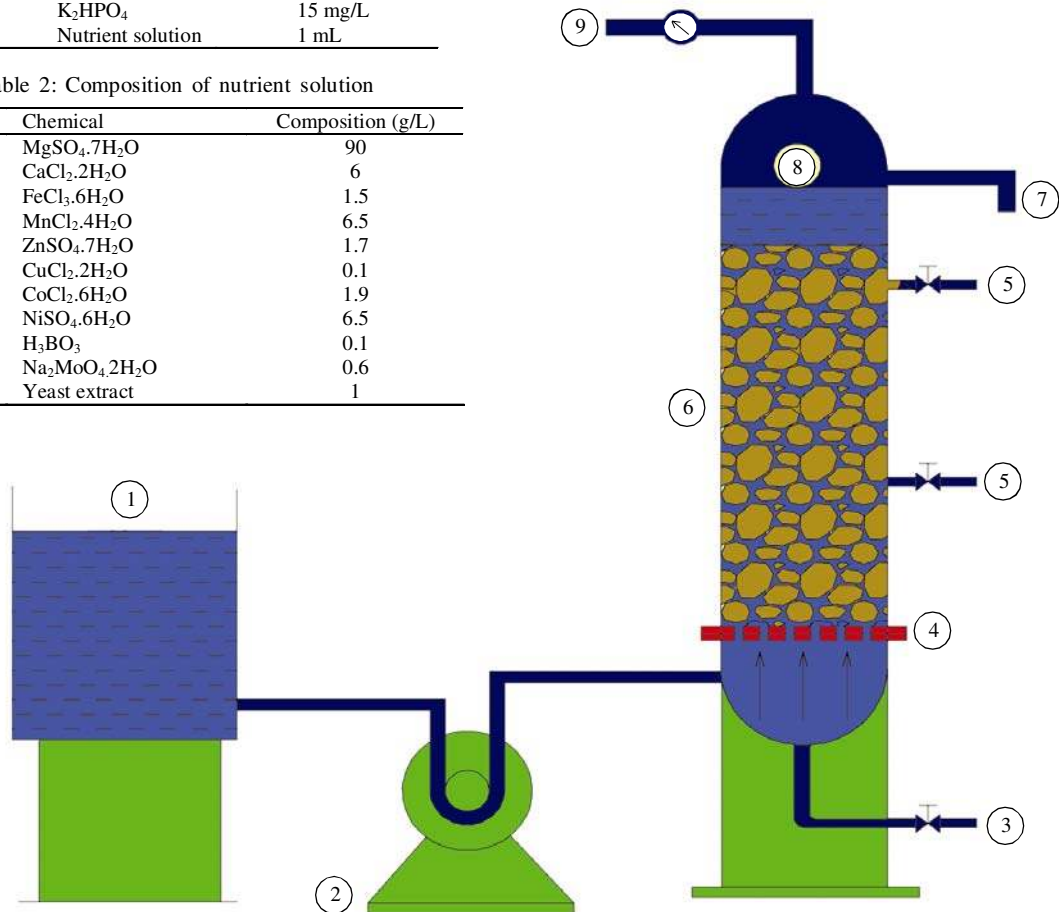

Fig. 1: Schematic of the experimental UFAB (1) Synthetic wastewater; (2) Peristaltic pump; (3) Draining port; (4) Perforated plate; (5) Sampling port; (6) Filter media; (7) Effluent outlet; (8) Liquid hold-up; (9) Gas collection and measurement

Experimental procedure

The required composition of synthetic fertilizer wastewater was prepared to a volume of 8 L and passed into the bioreactor at the required flow rate (0.66, 0.44, 0.33 L/h) with the help of a peristaltic pump. After acclimatization, during continuous experiments the influent NO_3-N concentration was gradually increased in steps of 50 mg/L. 16 gm of topioca starch powder was added to 8 litres of synthetic fertilizer wastewater. Similarly when carbon source was changed to ethanol, 6.25 mL of ethanol was added to 8 litres of synthetic fertilizer wastewater. These amounts were taken by determining the COD values of topioca starch and ethanol. The dissolved oxygen values were maintained in the range of 0.6 to 1 mg/L. The HRT was varied between 12-24 h, while the NO3-N concentrations were between 50-250 mg/L depending on the carbon source. COD and NO_3-N analysis were performed according to the procedure outlined in Standard Methods (APHA, 1992).

RESULTS

To understand the denitrification performance in UFAB using two different carbon sources, a synthetic wastewater of a known composition was fed to the bioreactor. During the start-up period the pH of the influent and effluent was monitored and was found to be fluctuating in a normal way (7-7.8). 33 days of acclimation was considered sufficient for the bioreactor based on the results. During this period, glucose was used as the carbon source. A near steady state was observed in % COD removal for about five days (Fig. 2) following which regular experiments were performed to monitor the effect of HRT and influent NO_3-N concentration on COD and NO_3-N removal. Fig. 3 shows the percentage NO_3-N nitrogen and COD removal efficiency variation with influent NO_3-N concentration when topioca starch was used as carbon source and HRT was 24 hours. As the influent concentration of NO_3-N nitrogen increases (50 to 150 mg/L) the NO_3-N nitrogen and COD removal efficiencies decreased.
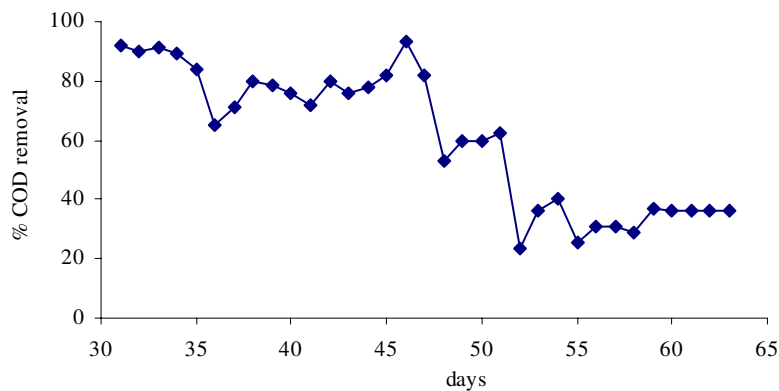

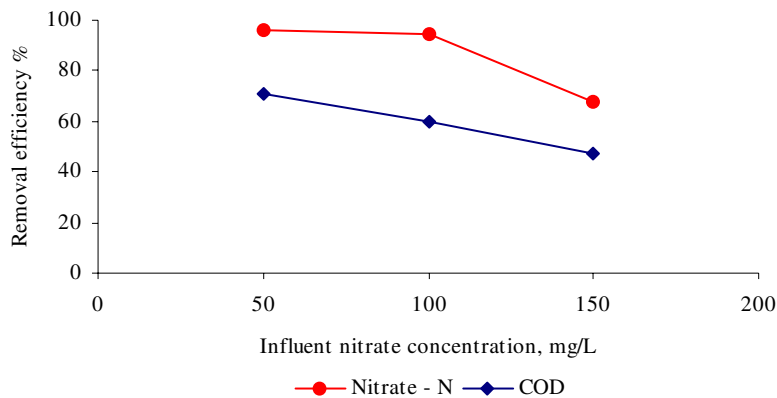Fig. 2: Start up and acclimatization of anoxic bioreactor

Fig. 3: Effect of Influent NO_3-N concentration on Removal efficiency
(Carbon source: Topioca starch, HRT: 24 h)

Fig. 4 shows the NO_3-N and COD removal efficiency variation with influent NO_3-N concentration when ethanol was used as carbon source and HRT was 24 h. As the influent concentration of NO_3-N nitrogen increases (50 to 250 mg/L) the NO_3-N nitrogen and COD removal efficiency decreased. Rajapakse and Scutt, 1999 investigated the treatment of synthetic wastewater (by dissolving $NaNO_3$ in tap water) using methanol as the carbon source. Their results reveal that, as influent NO_3-N nitrogen concentration increased, denitrification efficiency decreased. This tendency is similar to the present results of the synthetic fertilizer wastewater investigation carried out.

From these figures, it is evident that ethanol yields better denitrification efficiency compared to tapioca starch. When topioca starch was used as carbon source and influent concentration increased from 100 to 150 mg/L, NO_3-N nitrogen removal efficiency drastically reduced by 26.6 %, whereas when ethanol was used as the carbon source NO_3-N nitrogen removal efficiency is just reduced by 3.35 %.In the case of topioca starch as carbon source, it has to undergo hydrolysis as well as acid production stages before it becomes an alcoholic compound. But ethanol being a direct alcohol acts quickly and serves as a ready carbon source. Probably this is the reason for the enhanced efficiency in the case of ethanol as carbon source. The NO_3-N nitrogen and COD removal efficiency variation with HRT when topioca starch and ethanol were used as carbon source and influent NO_3-N concentration was 50 mg/L is shown in Figs. 5 and 6 respectively. It can be seen that the denitrification efficiency and % COD removal efficiency increased with increase in HRT.
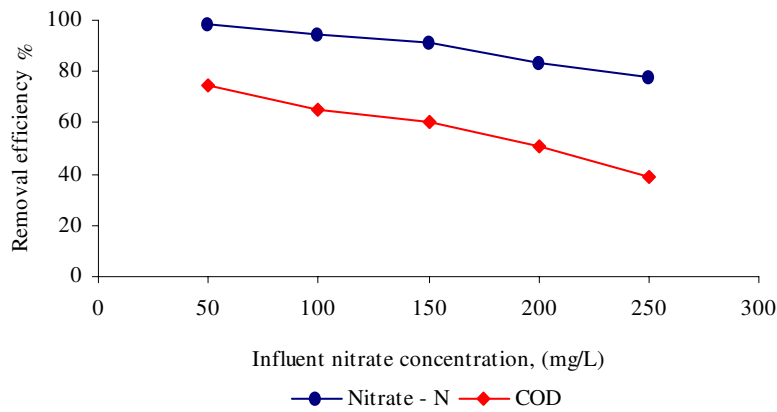

Fig. 4: Effect of influent NO_3-N concentration on removal efficiency
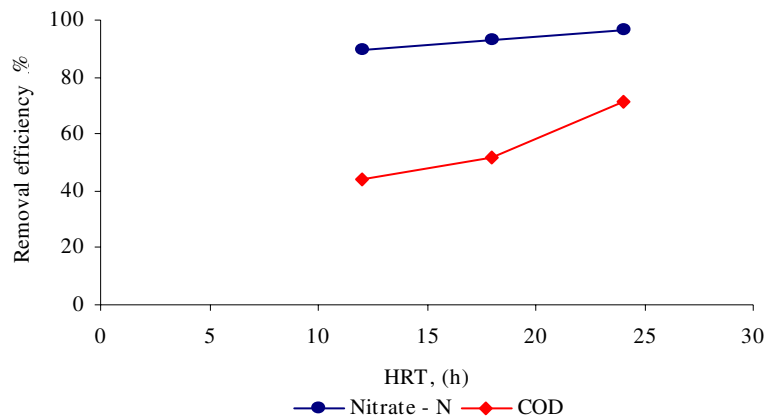(Carbon source: Ethanol, HRT: 24 h)

Fig. 5: Effect of HRT on removal efficiency
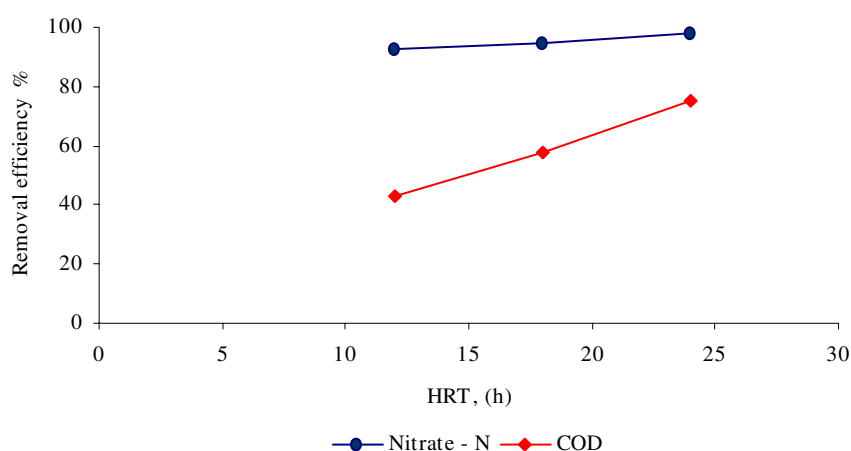(Carbon source: Topioca starch, Influent NO_3-N concentration: 50 mg/L)

Fig. 6: Effect of HRT on removal efficiency
(Carbon source: Ethanol, Influent NO_3-N concentration: 50 mg/L)

DISCUSSION AND CONCLUSION

An increase in NO_3-N concentration in the influent (50 to 250 mg/L) decreases the NO_3-N removal efficiency in UFAB. When topioca starch was used as the carbon source, denitrification efficiency reduced from 96.4 to 68 % while the denitrification efficiency reduced from 98.2 to 78 % when influent NO_3-N nitrogen concentration increased from 50 to 250 mg/L for ethanol. With increase in HRT, denitrification efficiency increases irrespective of type of carbon sources. But at minimum HRT of 12 h (taken in this study) ethanol yields better denitrification efficiency of 92.4 % compared to topioca starch of 89.5 % at same influent NO_3-N concentration of 50 mg/L. The results from this study can be applicable for treating topioca and ethanol laden wastewater in field applications.

ACKNOWLEDGEMENTS

REFERENCES

American Public Health Association (APHA), (1992). Standard Methods for the Examination of water and wastewater. 18th. Ed., Newyork.

Abu-Ghararah, Z.H., (1996). Biological denitrification of high nitrate water: Influence of type of carbon source and nitrate loading. J.Environ. Sci. Health., **A31** (7), 1651-1668.

Bilanovic, D., Battistoni, P., Cecchi, F., Pavan, P., Alvarezs, J.M., (1999). Denitrification under high nitrate concentration and alternating anoxic conditions. Wat. Res., **33**(15), 3311-3320.

Menoud, P., Wong, C.H., Robinson, H.A., Farquhar, Barford, J.P., Barton, G.W., (1999). Simultaneous nitrification and denitrification using Siporax™ packing. Wat. Sci. Tech., **40** (4-5), 153-160.

Rajapakse, J.P., Scutt, J.E., (1999). Denitrification with natural gas and various new growth media. Wat. Res., **33** (18), 3723-3734.

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