Study on nitrification and denitrification of high nitrogen and COD load wastewater in moving bed biofilm reactor

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Abstract
Removing nitrogen, as one of the most common and abundant pollutant of ground and surface waters is very important. For this purpose, biological nitrification and denitrification as the most economical method should be investigated. Feasibility of high load (Chemical Oxygen Demand) COD (1000-2000 mg/l) and NH_4 (1000-2000 mg/l) wastewater treatment, at different Hydraulic Retention Times (HRTs) was studied in two 9-lit anaerobic-aerobic system in pre-denitrification mode. Moving Bed Biofilm Reactor (MBBR) is a new system, having all the advantages of activated sludge, fluidized bed and fixed bed processes, without disadvantages of each system, that the biofilm production takes place on the packings, moving along the height of the reactor. From the experiments carried out in this system, result, showed higher ammonia removals take place at higher ammonia and lower organic loads. Denitrification increases at higher nitrification rates because of the increasing effect of NO_3^- entering the anaerobic reactor. In spite of the fact that nitrifying bacteria are more sensitive than COD and NO_3^- removing bacteria, after toxic shock by phenol as organic source, nitrification rate increases and COD removal decreases according to the damaging effect of phenol on COD removing bacteria. Total COD removal during the study varies between 80-100%, this value changes to 30-80% for ammonia and 30-80% for ammonia and 40-90% for nitrate.

Keywords: *Biological treatment, Denitrification, Moving Bed Biofilm Reactor (MBBR), Nitrification, Hydraulic Retention Time (HRT).*

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INTRODUCTION

Biological nitrification and denitrification are two of the most important processes used in wastewater treatment. Abundance nitrogen pollutant compounds in water and wastewater and also due to progressing procedure of population and increasing number of industrial plants and agricultural fields, specially in developing countries have been caused the difficult in water resources. Biological nitrification and denitrification are two of the most important processes used of wastewater treatment. It is generally believed that on relative basis ammonia and nitrite oxidation is carried out mainly by autotrophs particularly *Nitrosomonase sp.* and *Nitrobacter sp.* A few features of the autotrophic nitrifying bacteria, Nitrosomonase and Nitrobacter are summarized in table 1. During denitrification, nitrite reduction to N_2 is carried out by heterotrops of the *Pseudomonase sp*.

Biofilm process was proved to be more reliable than suspended systems for organic carbon and nitrogen removal with no problems of suspended growth system. The most cost-effective nitrogen removal will probably be achieved by using rather compact biofilm processes (Anthonisen *et al.*, 1976; Helmer *et al.*, 1999). A biofilm process, which may be compact, is the one based on submerged biological filters. There are many reports concerning the possibility of biofilm process for treating wastewater, but the disadvantage of this system is the possibility of clogging of the biofilm media (Chen *et al.*, 1995; Al-Ghusain *et al.*, 1994; Halling-Sorensen and Jorgensen, 1993; Huang *et al.*, 1992; Rusten *et al.*, 1994, 1996, 2000).

The biofilm process with a highly specific surface, and without the clogging problem is the moving bed

Table 1- Autotrophic characteristics of Nitrosomonase and Nitrobacter.

Character \ Microorganism	Nitrosomonase	Nitrobacter
Morphology	Rod-shaped	Rod-shaped
Cell size	1-1.5 μm	0.5 -1 μm
Gram Test	Negative	Negative
Autotroph	Obligate	Facultative
Dissolved oxygen requirement	Strict Aerobic	Strict aerobic
Optimum temperature	5-35 (^{o}C)	5-35 (^{o}C)
Optimum pH	7.8-9.2	8.2-9.2
Estimated generation time	8-36 (h)	12-59 (h)
Free-energy efficiency	11-27	34

biofilm reactor (Pastorlli *et al.,* 1999). In such reactor the biofilm is growing on a carriers circulating inside the tank. The carriers are shaped to maximize growth, by protecting the biofilm from abrasion (Van loosdrecht *et al.,* 1995; Yang and Zhang 1995). The moving bed biofilm process was developed about 10 years ago by the Norwegian company Kaldnes Miljiteknologie, in cooperation with SINTEF, a Norwegian research organization (Metcalf and Eddy, 1991). The basic idea behind the MBBR was to have a continuously operating, non cloggable biofilm reactor with no need for backwashing, low-loss and a high specific biofilm surface area (Chudoba and Pannier, 1994). Such reactor is becoming increasingly popular and is now being used in more than 100 plants around the world for various treatment purpose (BOD/COD removal, nitrification, denitrification) in both municipal and industrial wastewater (Yang and Zhang, 1995; Hem and Rusten, 1994).

This paper presents the results obtained from two pilot anaerobic-aerobic MBBRs plants in their application in both organic carbon and nitrogen removal.

MATERIALS AND METHODS

Technical and operating data, and a simplified flow sheet of the pilot plant are shown in table 2 and figure 1 respectively. The pilot plant was operated in the predenitrification mode, with two reactors in use. The first reactor was always anaerobic and the second one was aerobic. The process is based on the biofilm principle and the biomass grows on small elements that move along with the wastewater in reactor. The movement is typically produced by coarse bubble aeration in aer-

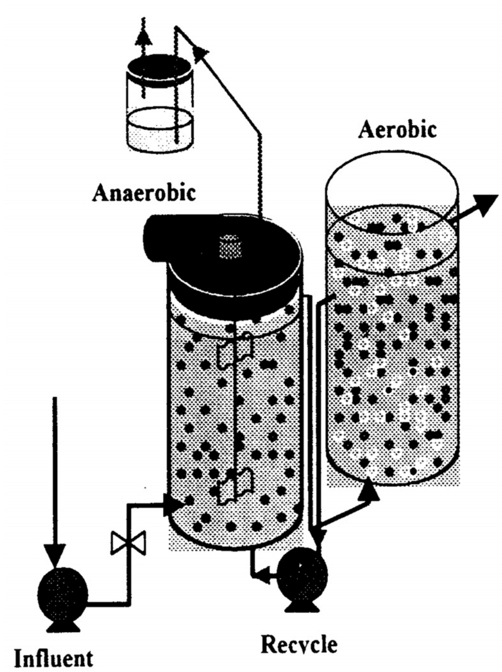

Figure 1. Two anerobic-areobic MBBRs.

Table 2- Technical and operating data of pilot-plant.

Pilot-plant / Technical Dates	MBBR	Feed Tank
Height	54 cm	62 cm
Diameter	15 cm	33 cm
Volume	9 lit	50 lit
Shaft height	48 cm	-
Impeller diameter	10 cm	-
Filling ratio	60%	-
Electromotor	DC, 5 Amp., 40 Volt	-
Aeration	Coarse Bubble	-

obic and mechanical mixing in anaerobic reactor. The biofilm carrier elements are made of 0.9 specific gravity of polyethylene, with about 13 mm long and 13.5 mm in diameter (Fig. 1).

Both reactors were filled 60% in volume, providing specific surface area equal to 192.5 m^2/m^3. As shown in figure 1, two series of anaerobic-aerobic reactors were operated in pre-denitrification mode to study the feasibility of treating high nitrogen and COD load wastewater without extra expense to add external carbon source to provide high C/N ratio for denitrification process. This configuration also helps to reduce influent COD to nitrification reactor that causes high rate nitrification. Technical and operating data of the pilot-plant are given in table 2.

Experiments were carried out to study the effect of HRT, COD load and NH_4^+ load on nitrification and denitrification rate in 3 HRTs, 3 COD loads in each HRT and 4 ammonia concentrations for each COD load. The process was tested in pilot plant for treatment of high nitrogen and COD load. The composition of synthetic wastewater is: [NH_4-N: 100-700 (mg/l), COD: 1000-2000 (mg/l), NO_3-N: 0-10 (mg/l)]. NH_4HCO_3 and NH_4Cu were used as ammonia source and phosphorous was provided by adding KH_2PO_4. NH_4HCO_3 and KH_2PO_4 were chosen as buffer compounds to control the pH of process. Micronutrients such as Cu^{2+}, Cl^+, Mg^{2+}, Na^+ and Fe^{2+} were added to the system as $CuSO_4$ (2 mg/l), $MgSO_4$ (3 mg/l), $FeCl_3$ (0.4 mg/l), and NaCl (0.7 mg/l). Temperature and pH were measured in each bioreactor every working day, immediately before sampling. Sampling of the influent wastewater and the content of the MBBR at the end of anaerobic and aerobic were taken everyday. The samples were analyzed immediately after sampling for the parameters shown in table 3. The parameters were measured according to the Standard Methods (APHA. (1995). GF/C Whatman and 0.45 µm filters were used for filtration of samples.

RESULTS

Batch operation: The experimental purpose is studying the behavior of the MBBR for COD removal and also simultaneous nitrification and denitrification during aerobic and anaerobic stages. The pilot plant was filled with primary wastewater (adding continuously organic and nitrogen sources), and operated under batch condition for two months.

The batch operation was used as start-up for growth of biofilm on carrier elements. After this period, the biofilm appeared on packing elements and MBBRs seemed to be ready for continuous operation. Characteristics of aerobic and anaerobic wastewater before continuous operation are given in table 3.

Table 3. Characteristics of wastewater in both systems before continuous.

System / Parameter	Anaerobic MBBR	Aerobic MBBR
COD (mg/l)	2543.75	1017.5
NH_4^+(mg/l)	100.5	50.25
NO_3^-(mg/l)	25.73	45.3
pH	7.9	9.2
MLSS (mg/l)	3400	1810
SVI (mg/l)	66.3	132

Continuous operation: For a period of 6 days, the pilot plant was operated at hydraulic retention time (HRT) of 30 hours, and recycle ratio 2, getting prepared for main start-up. Due to the high concentration of nitrate in the effluent, the recycle ratio was increased to 4, during the start-up period.

Experimental results for different HRTs, organic and nitrogen-loading rates are shown in figure 2 to figure 5.

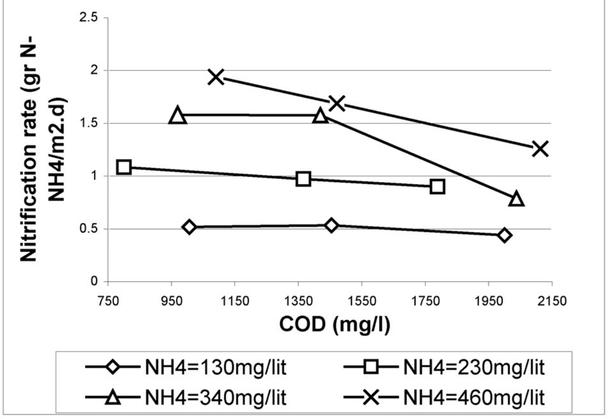

Figure 2-a- Nitrification rate vs. influent COD (HRT= 20 h).

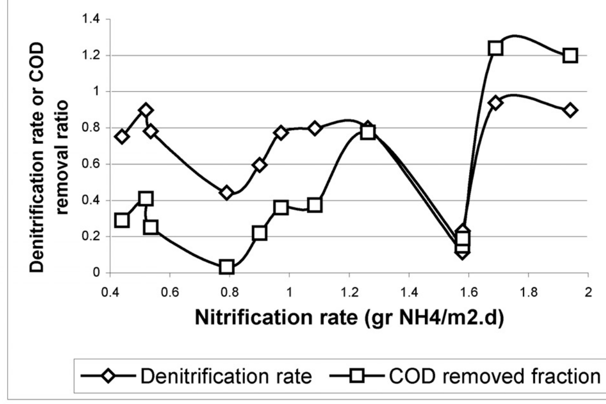

Figure 3-a- Procedure of COD removed fraction and nitrification rate (HRT= 20 h).

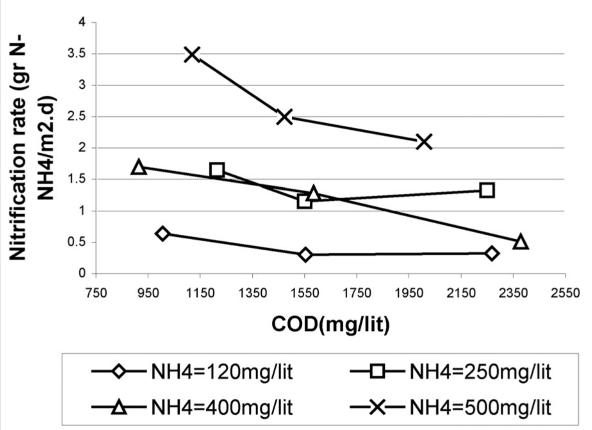

Figure 2-b-Nitrification rate vs. influent COD (HRT= 14 h).

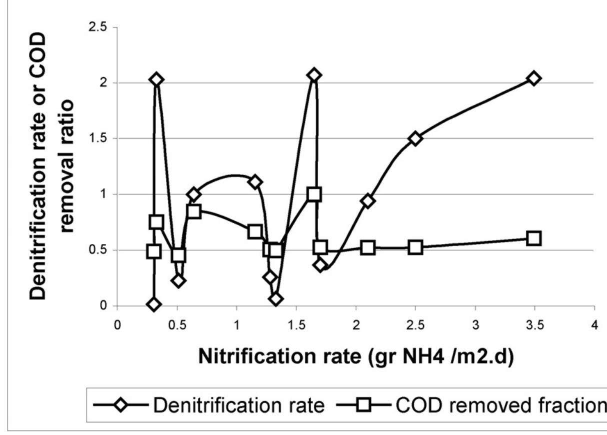

Figure 3-b- Procedure of COD removed fraction and nitrification rate (HRT=14 h).

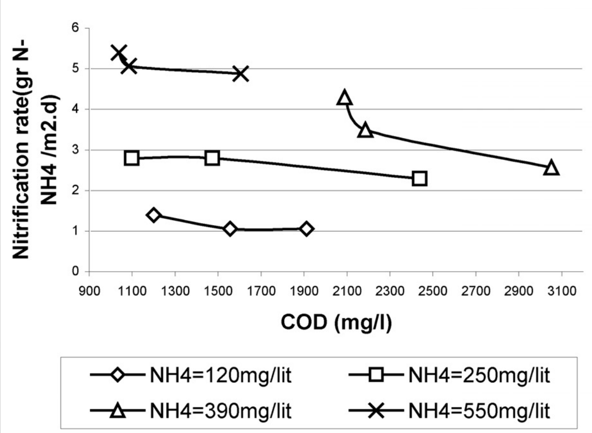

Figure 2-c- Nitrification rate vs. influent COD (HRt= 8 h).

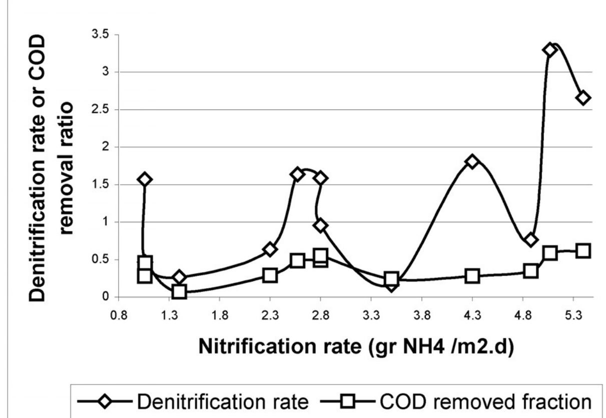

Figure 3-c- Procedure of COD removed fraction and nitrification rate (HRT= 8 h).

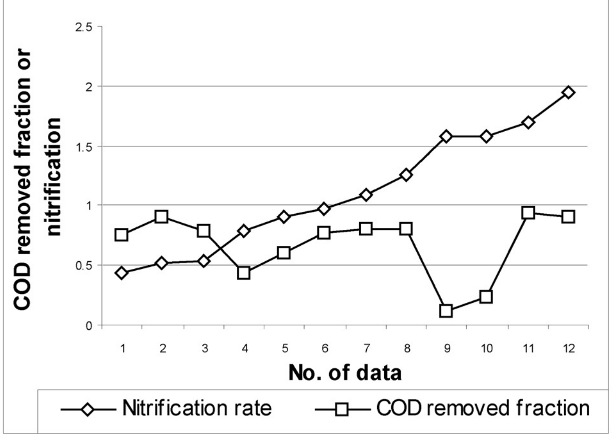

Figure4-a- Procedure of COD removed fraction and Denitrification rate (HRT= 20 h).

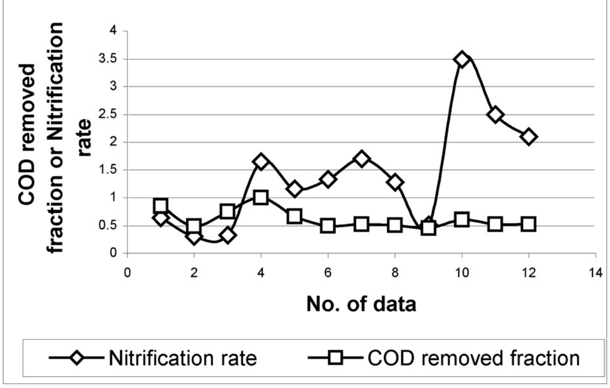

Figure 4-b- Procedure of COD removed fraction and denitrification rate (HRT=14 h).

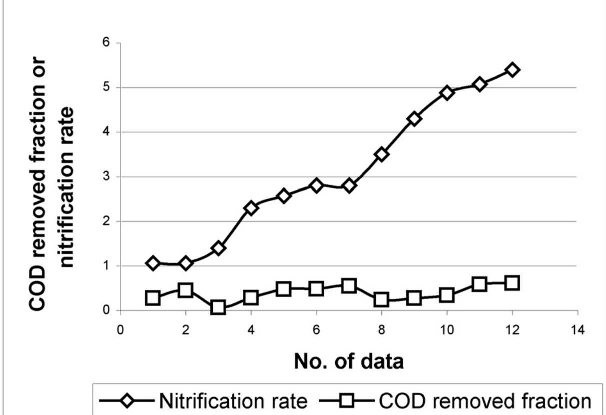

Figure 4-c- Procedure of COD removed fraction and denitrification rate (HRT= 8 h).

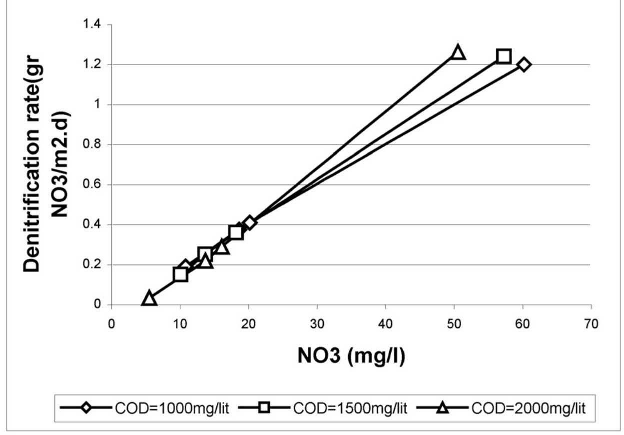

Figure 5-a- Denitrification rate vs. NO3 (HRT= 20 h).

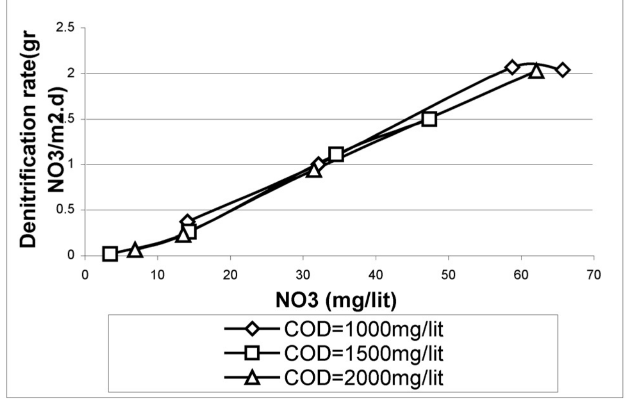

Figure 5-b- Denitrification rate vs. NO3 (HRT= 14 h).

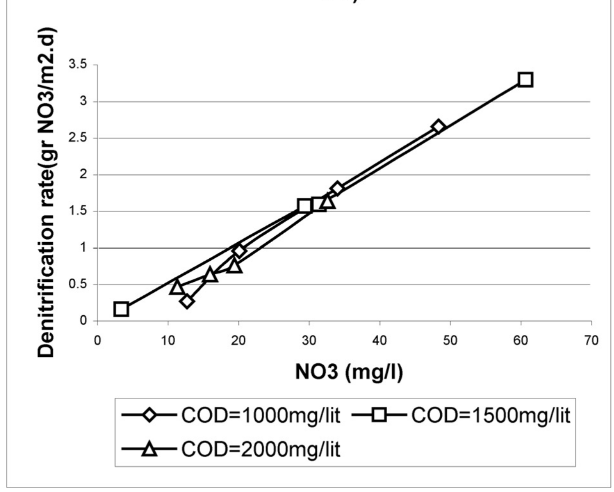

Figure 5-c- Denitrification rate vs. NO3 (HRT= 8 h).

DISCUSSION

As shown in figure 2 (a, b, c), nitrification rate decreases when COD increases. Also it can be seen that the results for higher ammonia loads has more affected than the others. It can be concluded that the competitive inhibition effect at high COD loads influenced on nitrifier bacteria, which compete with carbonaceous bacteria in high COD loading rates. At higher ammonia loads it is easier for nitrifiers to compete with the other microorganisms, to consume the dissolved oxygen in the system. Nitrification rate has dual effect on COD removal. On one hand COD removal decreases when high nitrification rate occurs because of the higher activity of nitrifiers. On the other hand when nitrification rate increases more nitrate enters the anaerobic reactor and as a result more denitrification and subsequently more COD removal is achieved.

These results can be also concluded from figures 4 (a, b, c), which show the same procedure of COD removal and denitrification and nitrification rates. Effect of nitrate concentration on denitrification rate was shown in figure 5 (a, b, c). Another important result obtained is that the influence of nitrate concentration is more important than C/N ratio and is one of the most important factors on denitrification rate. Other results show low sensitivity of MBBR to HRT and insignificant effect of HRT change on COD removal, denitrification and nitrification process, which show high stability of MBBR.

CONCLUSIONS

From different tests in pilot-scale plants, the following experiences have been obtained with MBBR:

1) The reactor has demonstrated its capability for nitrification, denitrification and organic removal process of a broad range of ammonia and COD.

2) Major advantages of MBBR as compared to other systems are simplicity in operation, low space requirement, stability, reliability, good settlability, low head loss, no bulking and lack of backwash requirement.

3) Percent of COD removal was almost above 85%.

4) Ammonia and nitrate removals were above 50 and 70% respectively.

5) HRT changes did not have any significant effect on the performance of system.

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