PERFORMANCE OF A MOVING BED SEQUENCING BATCH REACTOR FOR CARBON AND NUTRIENT REMOVAL

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SUMMARY

The aim of this study was to investigate the performance of a Moving Bed Sequencing Batch Biofilm Reactor (MBSBBR) with regard to organic matter removal and nitrification. Within the scope of this study, the kinetic constants for organic matter removal and nitrification in a lab-scale MBSBBR fed with a synthetic influent of domestic wastewater characteristics were determined. The evaluation of the results revealed that removal of organic matter at high rates and with efficiencies over 90% was secured at all operational conditions applied. Full nitrification was obtained with a rate of 0.241 g NO_X-N/m^2.d^{-1} at 20 °C. The autotrophic growth rate was determined to be 0.50 d^{-1}.

KEYWORDS:
MBSBBR, nitrification, carbon removal, process kinetics.

INTRODUCTION

Suspended growth biological treatment systems like activated sludge processes, aerated lagoons and biofilters, although widely used for wastewater treatment, face severe operational difficulties. In recent years, studies focusing on hybrid systems combining the advantages of suspended growth and biofilm systems have increased. Several pilot and full-scale studies concluded that these systems have advantages over conventional systems due to their increased total biomass improving substrate removal ability, performance during shock loads, performance of clarifiers, nitrification, reduction in sludge production, reduced reactor volume requirement and/or energy and cost efficiency [1-4].

A moving bed biofilm reactor (MBBR) is a continuous biofilm reactor operated with a low head loss and a high specific biofilm surface area. It offers the advantages of the biofilm process (compact and stable removal efficiency, simplicity of operation) without its drawbacks (channeling and clogging of the medium). There is no need for backwashing or recycling of the biomass. In this system, the biofilm grows on small carrier elements that move along with the water in the reactor by aeration (aerobic stage) or by mechanical stirring (anoxic/ anaerobic stage). Existing overloaded treatment plants can be easily retro-fitted by MBBR methodology into nutrient removal systems.

Similar as in all fixed-film systems, the superiority of MBBR is the ability to sustain a substantially higher biomass in the same reactor volume, when compared to suspended growth activated sludge processes. The main design parameters of the system are defined as the *filling ratio* and the *specific biofilm surface area,* together with the hydraulic retention time and the overall volumetric loading rates expressed as organic carbon and ammonia nitrogen. Dissolved oxygen concentration and temperature are also important parameters affecting carbon and nitrogen removal efficiencies.

In the last decade, research has been carried out on pilot and full-scale MBBR systems, especially examining their removal of organics and nutrients from domestic and industrial wastewaters [5-11]. These studies investigated the influence of various operational parameters on the treatment efficiencies in continuous systems. However, specific studies determining the kinetic constants for the removal of organic matter and nutrients, which are very important for the description and efficient application of such systems, are still insufficient.

Sequencing Batch Reactors (SBRs) are systems with significantly reduced land requirement, since various processes can take place in a single reactor. Ease in adjusting operational conditions and flexibility of operation, thus, achieving elevated treatment efficiencies, are the most important advantages of these reactors. Wilderer [12] firstly

suggested to operate MBBRs in a sequencing batch mode in order to benefit from the advantages of SBRs. But studies on *Moving Bed Sequencing Batch Biofilm Reactors* (MBSBBRs) are quite limited.

The aim of this study was to investigate the organic matter removal and nitrification performance of MBSBBRs. Therefore, the kinetic constants for the removal of organic matter and nitrification were determined in a lab-scale MBSBBR with a synthetic influent prepared to simulate domestic wastewater characteristics.

MATERIALS AND METHODS

Experimental Setup

The experiments were carried out in a 10 L cylindrical Plexiglas MBSBBR placed in an incubator in order to operate constantly at 20 °C (Fig. 1). The wastewater was fed and discharged by peristaltic pumps with timer controls. The system was operated applying three cycles per day. These cycles consisted of three phases: Filling (30 min), aerobic reaction (420 min) and discharging (30 min).

FIGURE 1 - Experimental setup.

Carrier Elements

KMT® (Kaldnes Miljøteknologi AS, Norway) carrier elements were used for biofilm growth (Figure 2). Table 1 summarizes the properties of the carrier elements.

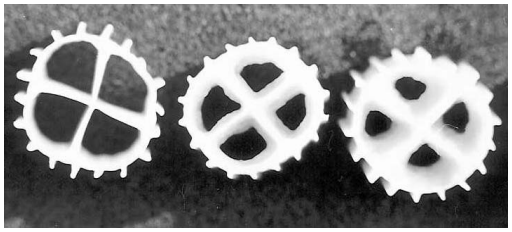

FIGURE 2 - KMT carrier elements.

TABLE 1
Physical properties of KMT carrier elements.

Density	0.95 g/cm^3
Average weight	0.1547 g
Diameter	9 mm
Filling ratio	70%
Useful specific surface area	350 m^2/m^3

Wastewater

The MBSBBR was fed with synthetic wastewater, which has 400 mg COD/L and 40 mg NH_4-N/L. The synthetic wastewater used in the study was prepared predominantly with acetic acid representing approximately 40 % of the total COD, followed by propionic acid, glutamic acid and glucose (each about 17%), and then ethanol with less than 10%. The reactor was operated with an organic loading of 3.01 g COD/m^2.d^{-1} and an ammonia loading of 0.30 g NH_4-N/m^2.d-1.

Experiments

COD measurements were carried out as described in ISO 6060 method [13]. For soluble COD (S_COD) determinations, the samples were subjected to vacuum filtration by means of Millipore membrane filters with a pore size of 0.45 µm. Millipore AP40 glass fiber filters were used for total suspended solids (TSS) and volatile suspended solids (VSS) measurements. The NH_4-N experiments were performed as defined in the Standard Methods [14]. NO_X-N concentrations were determined using a ChemLab Autoanalyzer, and the parameters of respirometric experiments, the maximum heterotrophic growth rate and yield coefficient, using a Manotherm RA 1000 respirometer. For the assessment of the maximum heterotrophic growth rate, $\hat{\mu}_H$, the batch tests were run at an F/M ratio of 4-5 g COD/g VSS as recommended by Kappeler and Gujer [15]. The heterotrophic yield, Y_H, was evaluated by comparing the OUR and COD profiles obtained for the same sample in accordance with the method proposed by Ubay Çokgör [16]. The tests were started with the biomass seeding alone to obtain the initial endogenous oxygen uptake rate (OUR) level. At a food/microorganisms (F/M) ratio of 0.125, the synthetic wastewater sample was added to the biomass in the reactor together with a nitrification inhibitor (Formula 2533™, Hach Company), and the OUR data were monitored. The maximum autotrophic growth rate, $\hat{\mu}_A$, was

determined by the method of Dold (1999) [17], using the slope of trendline-obtained data from NO_X-N measurements during the aerobic reaction phase.

RESULTS AND DISCUSSION

Organic Matter Removal

Evaluation of the results revealed a high organic matter removal with an efficiency over 90%. As can be seen in Figure 3, soluble COD (S_COD) decreased from 400 mg/L to 30-40 mg/L in the first 30 min of the reaction period.

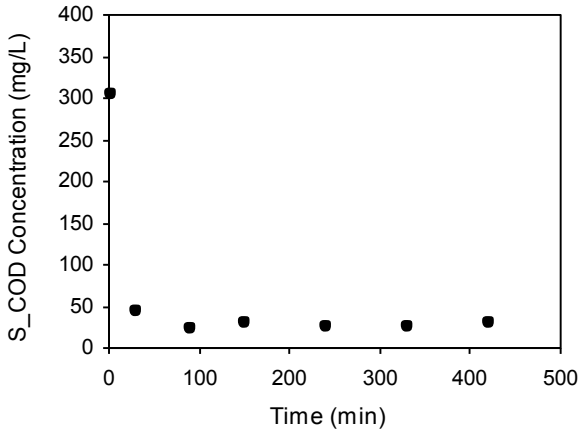

FIGURE 3 - Variation of S_COD concentration in a cycle.

OUR profiles obtained from respirometric experiments carried out with the suspended biomass portion of the system were used to calculate maximum heterotrophic growth rate, $\hat{\mu}_H$, (Fig. 4) and heterotrophic yield coefficient, Y_H, (Fig. 5). Maximum heterotrophic growth rate was calculated by the following equation:

$$\ln\left(\frac{OUR_t}{OUR_0}\right) = (\hat{\mu}_H - b_H)\cdot t \qquad \textbf{(1)}$$

Using the slope of trendline in Fig. 4, we can calculate:

$$0.00323 = (\hat{\mu}_H - b_H) \qquad \textbf{(2)}$$

$\hat{\mu}_H$ value was determined to be 4.75 d^{-1} assuming that the endogenous respiration rate, b_H, is 0.1 d^{-1}. This value compares well with the maximum heterotrophic growth rate for domestic sewage reported to range from 3.4 to 6.5 d^{-1} with a mean value of 4.8 d^{-1} [18].

Heterotrophic yield coefficient, Y_H, was calculated by the following equation using ΔO_2, which is the area between OUR profile and b_H level in Fig. 5:

$$Y_H = 1 - \frac{\Delta O}{\Delta S_S} = 1 - \frac{185}{400} = 0.54\ gCOD/gCOD \qquad (3)$$

This result is in good agreement with that of a similar study [19].

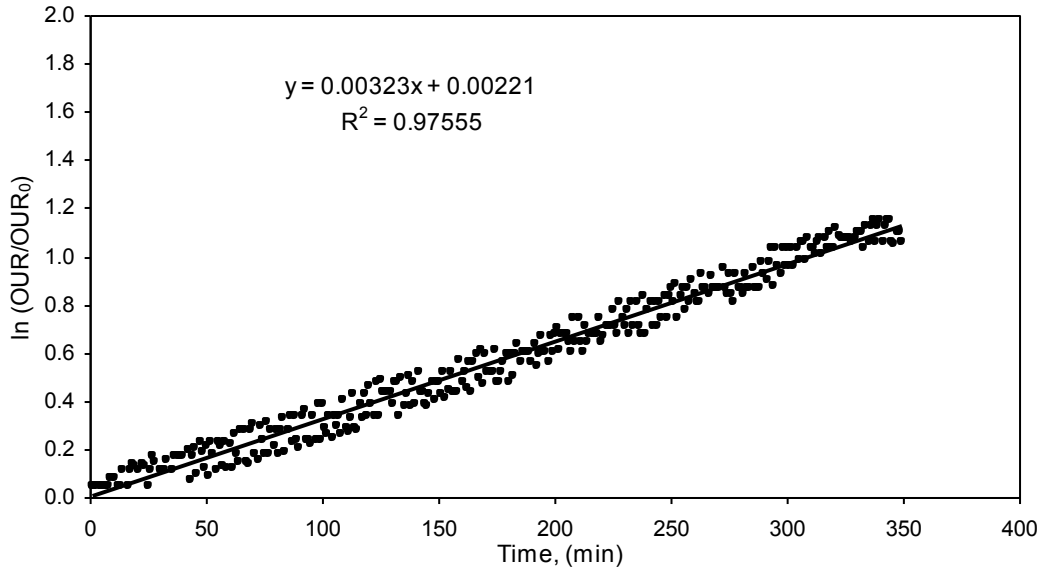

FIGURE 4 - OUR profile obtained from $\hat{\mu}_H$ experiment.

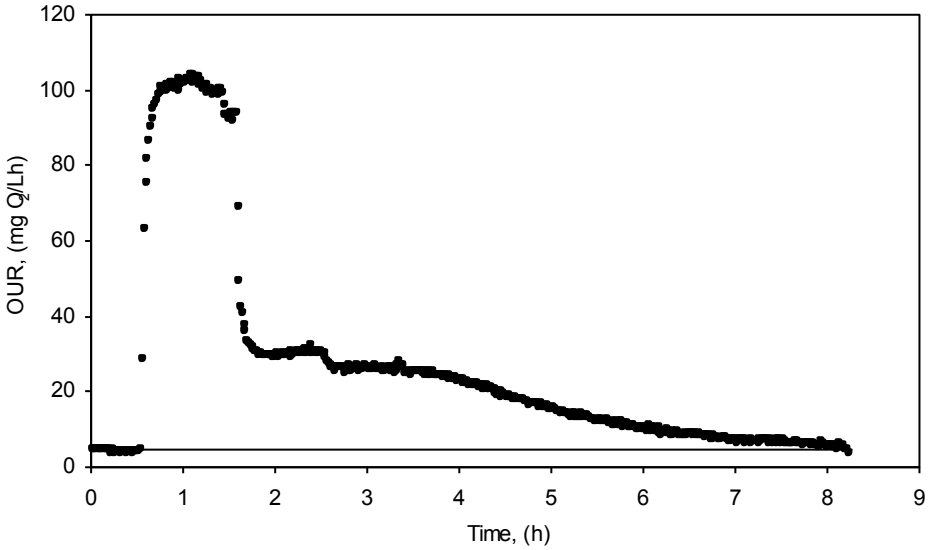

FIGURE 5 - OUR profile obtained from Y_H experiment.

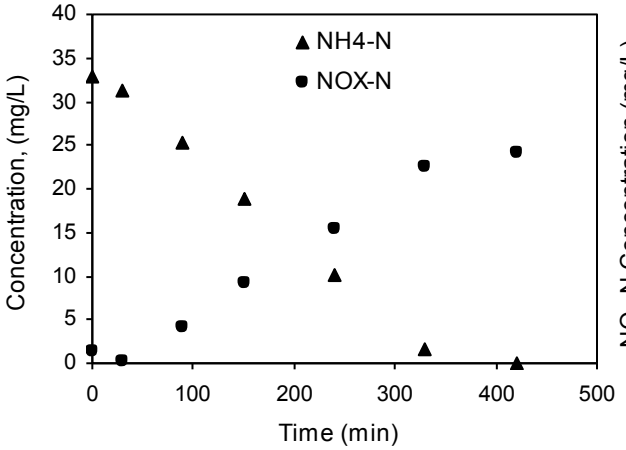

FIGURE 6 -NH_4-N and NO_X-N variations in a cycle versus time.

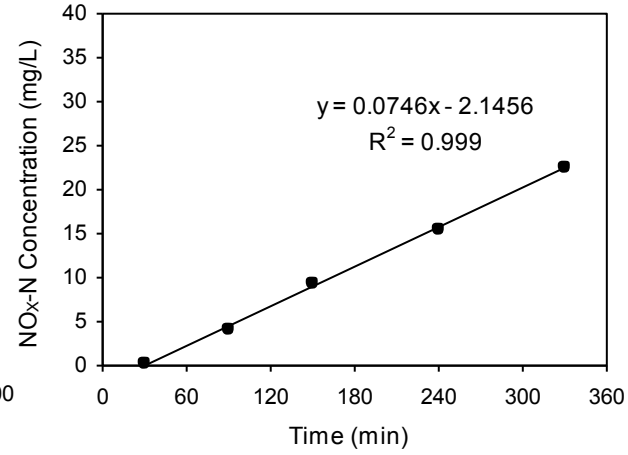

FIGURE 7 - Slope of NO_X-N concentration.

Nitrification

As can be seen in Figure 6, full nitrification was achieved with a rate of 0.241 g NO_X-N/m^2.d^{-1}. The maximum autotrophic growth rate, $\hat{\mu}_A$, was determined to be 0.50 d^{-1} using the slope obtained from the graph given in Fig. 7. This $\hat{\mu}_A$ value compares well with the range of 0.37-1.00 d^{-1} defining the maximum autotrophic growth rate for domestic and synthetic wastewaters in the literature [18, 20, 21].

CONCLUSION

The experimental results obtained in this study using a lab scale MBSBBR system fed with synthetic domestic wastewater indicate that:

- High organic matter removal was achieved with an efficiency higher than 90%.
- Maximum heterotrophic growth rate and heterotrophic yield coefficient were determined to be 4.75 d^{-1} and 0.54 g COD/g COD, respectively.
- The nitrification rate was 0.241 g NO_X-N/m^2.d^{-1} at 20 °C.

- Maximum autotrophic growth rate was determined to be 0.50 d^{-1} at 20 °C.

It is highly recommended that further considerations focus on the behavior of MBSBBRs, their heterotrophic and autotrophic activities, and, specifically, the determination of their heterotrophic and autotrophic kinetic constants with regard to municipal and different industrial wastewaters.

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