BIOFILM PROCESS WITH A SUPPORT PERMEABLE TO GASES, USING AIR

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ABSTRACT

The general objective of this research is the development of a new process based on a biofilm placed over membranes permeable to gases (but not to liquids), using air as the oxygen source, for the removal of carbonaceous substrate and ammoniacal nitrogen. A laboratory plant was operated using synthetic wastewater. The greatest efficiencies for COD and nitrogen removal were 74% and 62% respectively and the maximum removal capacities were 181 g COD/m^2.d and 47,3 gN/m^2.d. These results were compared to those obtained with the same process using oxygen instead of air. The process with air had a higher efficiency for the nitrogen removal than the process with pure oxygen, but the oxygen process has greater capacity and efficiency for the removal of carbonaceous organic matter.

Hydraulic retention times of 0,32 hours greatly reduced the system efficiency. The carbon/nitrogen relation had irregular effects on nitrogen removal, but determined the proportion between the quantities of carbonaceous organic matter and nitrogen removed.

KEYWORDS

Biofilm, membrane, air, oxygen, biological wastewater treatment, heterotrophic, oxidation, nitrogen removal.

INTRODUCTION

Biofilm reactors with membranes permeable to gases but not to liquids as the biofilm support were used in this study. In this type of reactor the supporting membrane is submerged. The biofilm developes over the membrane face in contact with the water. The biofilm consumes the oxygen supplied through the membrane and the substrate dissolved in the water.

The main advantages of these reactors should be: to obtain higher organic and nitrogen loads removed than those obtained in common processes, to produce a combined removal of organic carbon and nitrogen with simultaneous nitrification and denitrification; to produce less sludge; to use the exact and necessary quantity of oxygen, without losses; and to use less space. Despite all these advanteges, the cost of this type of membrane at the moment makes these reactors uneconomic. Nevertheless, the biofilm obtained in this process is an unconventional biofilm (countercurrent flow of donors and acceptors of electrons) and could be of interest for research.

Biofilm processes with a support permeable to gases using oxygen have been studied before. Onishi et al. (1982) patented a process with hollow fibres as support. Timberlake et al. (1988) obtained heterotrophic aerobic oxidation, nitrification and denitrification in a single biofilm with low organic carbon and nitrogen loads removed and high hydraulic retention times. Abdel-Warith et al. (1990) undertook a study to define the conditions under which the different phenomena will occur. They found anaerobic fermentation since they detected significant quantities of methane ucing high substrate concentrations in the influent. Eguía (1991) studied the organic carbon removal. In his experiments organic loads removed as high as 160 g. DQO/m².day were achieved.

The change from oxygen supply to air would be of major interest in order to reduce costs of maintenance. Hence, the objective of this research was to know: a) How the use of air affected the behaviour of the process, comparatively with the use of oxygen; b) How the carbon/nitrogen ratio (C/N) influenced the nitrogen removal; c) How low hydraulic retention times affected the performance of the process.

MATERIALS AND METHODS

Two laboratory-scale reactors were constructed for these experiments (Fig 1). Biofilms were supported on hydrophobic polytetrafluorethylene membranes (Millipore, PTFE-FGLP), with an area of 628,32 cm² each and a bubble point of 0,91 bar. Total volumes of reactors 1 and 2, considering the membrane deformation produced by the inner pressure ("sail effect") were 10,7 dm³ and 1,5 dm³, respectively. Complete mixing in the reactors was achieved by the use of proper impeller systems.

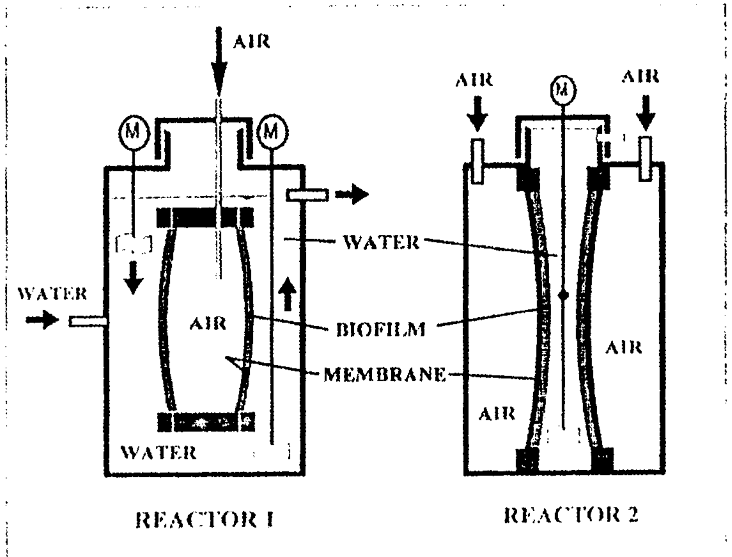

Fig. 1. Schematic layout of reactors

The biofilm oxygen source was air, supplied by means of compressed air bottles, introduced into each air compartment. Maximum pressure was 0,35 bar. Maximum oxygen consumption rate by the biofilms was controlled by installing control valves in each air supply tube. In this way, air was diffused through the membranes without producing bubbles in the water inside the reactors.

Wastewater used in the experiments was artificially prepared, using glucose as carbon source and ammonium chloride as nitrogen source. Various proportions of these components were employed in order to obtain different values for the relationship C/N.

Organic loads of 75, 150 and 300 g COD/m².day were used in the experiments, with influent COD of 200 and 400 mg/l. Values of 1,5; 3,1; 6,2, 12,5 and 25 were adopted for the carbon/nitrogen ratio, expressed as COD/N, in the different series of experiments. Consequently, nitrogen loads ranged from 6 to 96 gN/m².day. Hydraulic retention times (HRT) in the reactor varied between 0,36 and 10,9 hours. In some experiments the maximum oxygen consumption rate was reduced in order to mantain the dissolved oxygen concentration at very low values.

Twenty-three succesive experiments were carried out under controlled and constant conditions. Mean values registered at final steady state -considered as the state of zero or no significant variation with respect to substrate concentration- were adopted as the representative values for variables and parameters in each experiment. In addition, steps were taken to try to ensure that changes in the biomass, as a result of the change of feeding conditions in each experiment, were not appreciable in this final steady state.

Analytical techniques employed were those in Standard Methods. Total organic carbon (TOC) was determined using a specific automatic analyzer (OIC 700). Nitrate concentrations were determined using a selective electrode. Biofilm thickness was determined by means of microscopy and gravimetry.

RESULTS AND DISCUSSION

Very high organic load removals were obtained (from 40,4 to 181,4 g. COD/m².d.), although the mean efficiency ranged from 44 to 74 per cent. The kinetics for the carbon removal processes is that typical of biofilm processes (Fig 2). However, during the process with oxygen (Eguía,1991) kinetics was zero order and maximun organic carbon removal was obtained in all tests. When air was used, kinetics approached first order (k=0,9). The highest organic load removed was obtained for the highest COD.

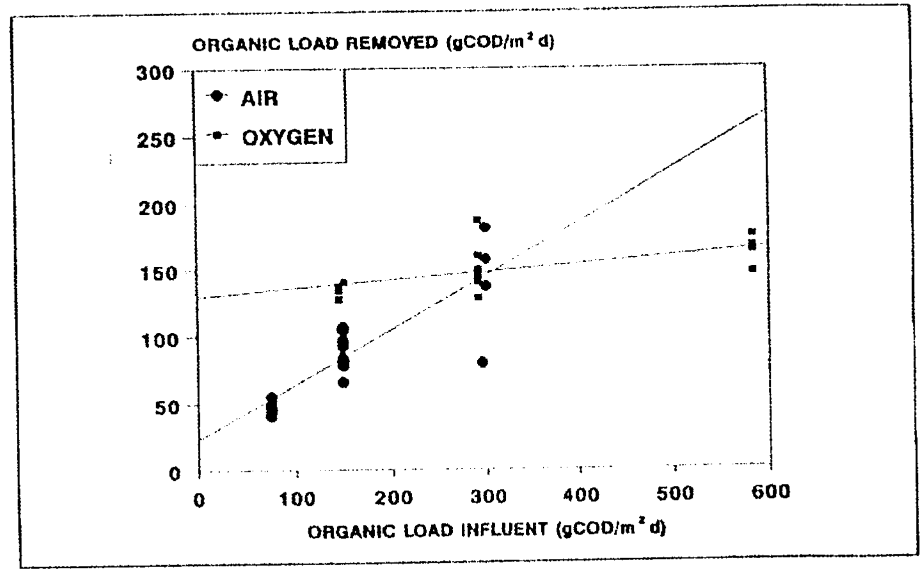

Fig. 2. Relationship between organic load influent and organic load removed

Significant acidification was detected when the reactor worked whith influent substrate concentrations of 400 mg/l of COD (pH from 4,45 to 5,76). This phenomenon did not occur at COD concentrations up to 200 mg/l (pH from 6,3 to 6,8). Acidification phenomena were not detected when oxygen was used instead of air (Eguía,1991).

[illegible] denitrification. Effluent nitrate concentrations from 0,0 mg/l to 0,9 mg/l were obtained. Nitrogen removal reached very high values (2,11 to 47,31 gN/m².d.), while the efficiencies oscillated between medium values and low values (23,2% to 68,1%). Apparently, a zero order kinetics and a first order kinetics were also found for nitrogen removal, using oxygen (Egufa,1991) or air respectively (Fig 3).

The operation of the reactor using oxygen (Egufa,1991) and air was compared under identical experimental conditions as follows: influent substrate concentration 200 mg COD/l, organic load 150 g COD/m².d, COD/N = 12,5 mg/l and HRT= 5,5 h.). The reactor removed more organic carbon using oxygen than

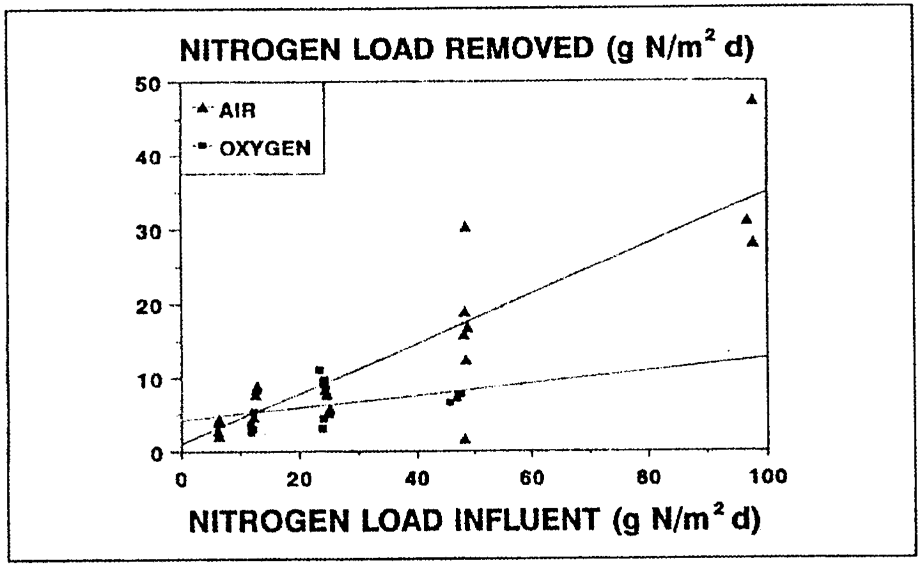

Fig.3 Relationship between nitrogen load influent and nitrogen load removed

using air (92% to 72%), inversely to the nitrogen removal (24,4% to 62,5%), which is in accordance with the previously deduced results.

Biofilm oxygen uptake was compared to reactor capability of oxygenation without the biofilm. Results indicate that usually the former is an order of magnitude above the latter. Assuming that biofilm adherence over the reactor membranes eliminates the turbulence generated by the impellers at the oxygen diffussion interface, oxygen transference derived from the turbulence itself does not occur in the reactor if its membranes are covered with a biofilm. In this case, oxygen transference must be due to the direct uptake at the membrane-liquid interface and to the microturbulence created by the biofilm's biocenoses. In addition, in this type of system both the interfaces liquid-biofilm and air-liquid, which usually represent a barrier for the oxygen diffussion, are avoided. This set of phenomena makes the "biological transference" of oxygen achieved with this process is of an order of magnitude above the average value obtained with the classical turbulent transference.

From the above statements is derived the possibility of making the reactor work without the artificial supply of air or oxygen at the membrane surface, as was later demonstrated by Lolmede (1992). Simply allowing natural aereation, the biofilm is able to take the oxygen directly from the atmosphere. A similar effect was observed in our experiments: when air flow was excessively reduced, air pressure inside the membrane diminished to the point of inverting the curvature produced by the "sail effect" in the membrane. The use of air instead of pure oxygen produced lower and variable oxygen partial pressures at the air compartment.

[illegible] oxygen. Hence, the higher penetration of dissolved oxygen into the biofilm and consequently its higher capacity for the removal of organic carbon, assuming the greater extent of a well-oxygenated biomass is deduced. However, the high dissolved oxygen levels at the inner biofilm layers, where the lowest organic carbon concentrations are reached and accordingly the best conditions for nitrifying organisms are provided, could create inhibitory conditions for this micoorganisms.

The biofilm worked with thicknesses from 1,4 to 4,1 mm. In addition to the influence of the organic loading over the film thickness, an analogous influence of biofilm age was detected. Thus, despite occasional oscillations, the biofilm thickness was growing throughout the experimental period. The dry density of biofilm was very high (80-100 g/l) but lower than that obtained using oxygen (Egufa, 1991).

Reactor 1 with a hydraulic retention time (HRT) seven times greater than reactor 2 performed the best in organic carbon removal and in nitrogen removal. With an HRT of 22 min an estimable decrease in performance was observed, but it did not occur with an HRT of 43 min.

The carbon to nitrogen ratio expressed as COD/N influenced the nitrogen removal irregularly (Fig 4), with some characteristics similar to those mentioned by Wu (1983). One difference is that we always obtained simultaneous nitrification-denitrification including for low values of the COD/N ratio, whereas they only obtained nitrification. Neither did we detect a decrease of nitrogen removal with high COD/N ratios.

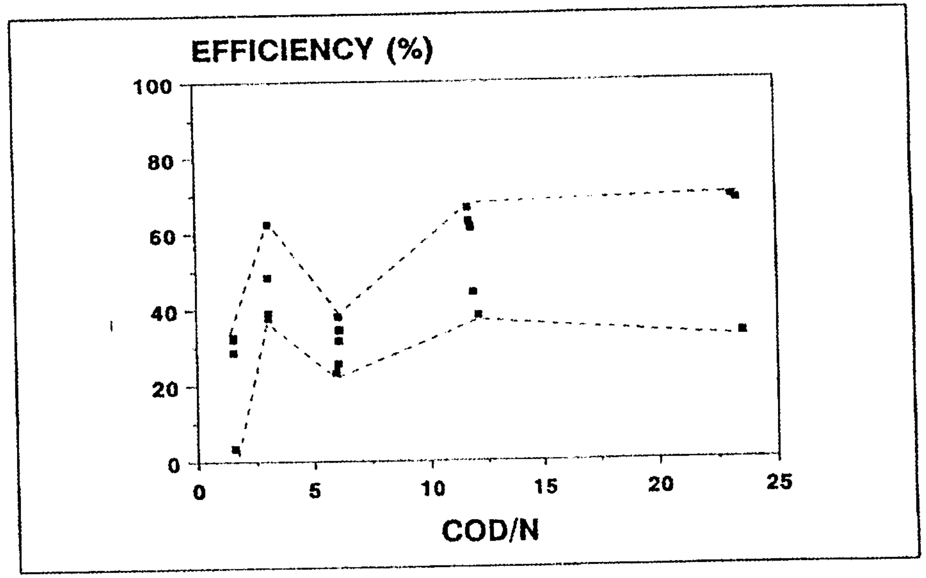

Fig. 4. Nitrogen removal efficiency vs COD:N ratio

The influent characteristcs, expressed as COD/N ratio, determined the proportion in which the process would remove carbon and nitrogen (Fig 5). This is consistent with the above results as regards the almost first kinetics obtained for organic carbon and nitrogen removal, characteristic of the process using air.

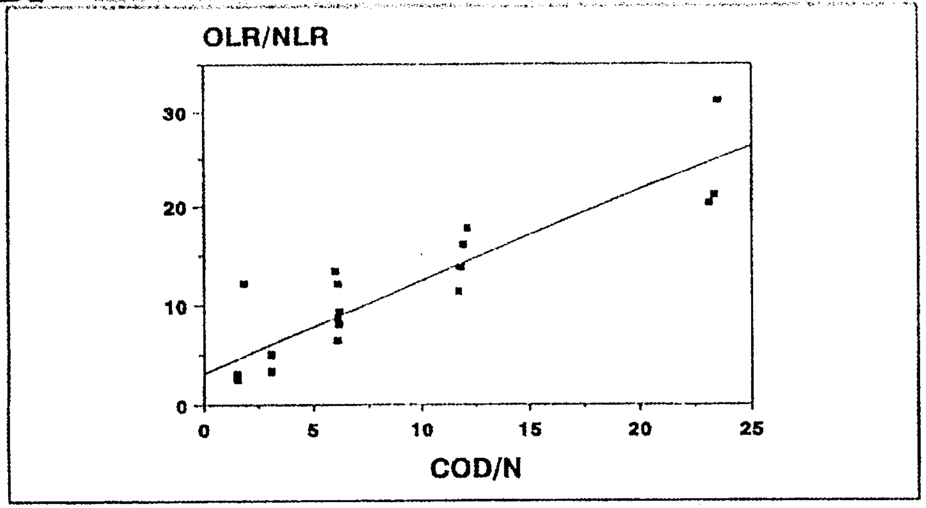

Fig. 5. Relationship between COD:N ratio vs organic load removed:nitrogen load removed ratio

CONCLUSIONS

The process using air achieves high organic carbon and nitrogen loads removed, but with low efficiency. The above process removes nitrogen better than the process operated with oxygen, although it is less efficient in organic carbon removal. The process using air can produce problems of bulk liquid acidification under certain conditions. These problems are not produced using oxygen.

The process with air can perform without the artificial supply of air, leaving the inner face of the membrane open to the atmosphere.

The organic carbon and nitrogen loads removed are in linear relationship with the influent C/N ratio.

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