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Comparative kinetic study between moving bed biofilm reactor-membrane bioreactor and membrane bioreactor systems and their influence on organic matter and nutrients removal

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ABSTRACT

New technologies regarding wastewater treatment have been developed. Among these technologies, the moving bed biofilm reactor combined with membrane bioreactor (MBBR-MBR) is a recent solution alternative to conventional processes. This paper presents the results obtained from three wastewater treatment plants working in parallel. The first wastewater treatment plant consisted of a membrane bioreactor (MBR), the second one was a MBBR-MBR system containing carriers both in anoxic and aerobic zones, and the last one consisted of a MBBR-MBR system which contained carriers only in the aerobic zone. The reactors operated with a hydraulic retention time of 26.47 h. During the study, the difference between the experimental plants was not statistically significant concerning organic matter and nutrients removal. However, different tendencies regarding nutrients removal are shown by the three wastewater treatment plants. In this sense, the performances in terms of nitrogen and phosphorus removal of the MBBR-MBR system which contained carriers only in the aerobic zone (67.34 ± 11.22% and 50.65 ± 11.13%, respectively) were slightly better than those obtained from another experimental plants. As a whole, the pilot plant which consisted of a MBR showed better performance from the point of view of the kinetics of the heterotrophic and autotrophic biomass with values of $\mu_{m,H} = 0.00858\ h^{-1}$, $\mu_{m,A} = 0.07646\ h^{-1}$, $K_M = 2.37\ mg\ O_2\ L^{-1}$ and $K_{NH} = 1.31\ mg\ N\ L^{-1}$.

1. Introduction

In the course of the last few decades, industrial development, increase in urbanisation and changes in farming practices, among other factors, have caused an outstanding rise in the consumption of water resources as well as deterioration in their quality.

As a consequence of this, and due to the more restrictive limits imposed to the effluent of municipal wastewater treatment plants by the Water Framework Directive [1], it has become necessary to improve existing municipal wastewater treatment plants. To achieve this, the development of more advanced technologies is necessary in order to comply with currently established effluent limits and water quality guideline as well as those that could be imposed in the future.

Water quality is influenced by several factors. Some of the most important are the organic matter content and the enrichment of nutrients in water bodies, like phosphorus and nitrogen [2]. Wastewater with high levels of organic matter, phosphorus and nitrogen can be the main reason for several problems when released into the environment, such as oxygen consumption, eutrophication and toxicity [3]. Accordingly, it is necessary to remove these contaminants from wastewater in order to reduce the damage caused to the environment [4].

Secondary treatment is the main process in a municipal wastewater treatment plant, with the aim of removing these contaminants. It is accomplished by biological processes classified into two different types: suspended biomass or biofilm processes. Suspended biomass processes are effective for the elimination of organic matter and nutrients in municipal wastewater treatment plants. The activated sludge process is the most commonly used suspended biomass process. However, these processes can have some drawbacks when exposed to high hydraulic and organic loads. To improve the performance of this process, the amount of biomass inside the reactor would have to be increased to the limitation imposed by the clarifier. Furthermore, sludge settleability, the large reactors and settling tanks required in these processes can be problematic [5].

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Nomenclature

BD	biofilm density
BOD_5	biochemical oxygen demand on the fifth day
COD	chemical oxygen demand
COD_b	biodegradable fraction of COD
f_{cv}	yield coefficient factor to convert to $mg\,VSS\,mg\,COD^{-1}$
f^*_{cv}	yield coefficient factor to convert to $mg\,VSS\,mg\,N^{-1}$
HRT	hydraulic retention time
k_d	endogenous or decay coefficient for autotrophic and heterotrophic biomasses
K_M	half-saturation coefficient for organic matter
K_{NH}	half-saturation coefficient for ammonia nitrogen
K_S	substrate half-saturation coefficient
MBBR	moving bed biofilm reactor
MBR	membrane bioreactor
MLSS	mixed liquor suspended solids
N	nitrogen concentration
OC	oxygen consumption
OUR	oxygen uptake rate
OUR_{end}	endogenous oxygen uptake rate
P	phosphorus concentration
r_d	cellular decay rate
r_{su}	substrate degradation rate
r_x	cellular growth rate
r'_x	net cellular growth rate
R_S	dynamic oxygen uptake rate
S	substrate concentration
S_{NH}	ammonium concentration
S_S	organic matter concentration
t	time
TSS	total suspended solids
VSS	volatile suspended solids
WWTP	wastewater treatment plant
X	biomass concentration
$X_{B,A}$	active autotrophic biomass concentration
$X_{B,H}$	active heterotrophic biomass concentration
X_T	total biomass concentration
Y	yield coefficient
Y_A	yield coefficient for autotrophic biomass
Y_H	yield coefficient for heterotrophic biomass

Greek symbols

μ	specific growth rate
μ_A	specific growth rate for autotrophic biomass
$\mu_{m,A}$	maximum specific growth rate for autotrophic biomass
μ_H	specific growth rate for heterotrophic biomass
$\mu_{m,H}$	maximum specific growth rate for heterotrophic biomass
μ_m	maximum specific growth rate
μ_{emp}	empirical specific growth rate

Membrane bioreactors can be highlighted as they solve most of the problems of conventional activated sludge systems. They combine membrane filtration and biological treatment using activated sludge, thus providing several advantages [6]. Firstly, the membrane replaces the clarifier in the wastewater treatment system [7,8]. Apart from this, these are compact systems with practically complete solids removal which permit effluent disinfection. Moreover, they can operate at higher suspended biomass concentrations, resulting in long sludge retention times as well as low sludge production and avoidance of problems regarding sludge bulking. However, fouling is a common problem of this kind of system, which is caused by the accumulation of substances on the surface of the membrane with a consequent reduction in membrane permeability [9].

On the other hand, biofilm processes have been proved to be reliable for organic matter and nutrients removal without suffering the typical problems of suspended biomass processes [10]. There are many different biofilm systems, such as trickling filters, rotating biological contactors, fixed media submerged biofilters, granular media biofilters, fluidised bed reactors, etc. They all have advantages and disadvantages [11,12].

For these reasons, the moving bed biofilm reactor process was developed in Norway in the late 1980s and early 1990s. In this study, a hybrid technology between a moving bed biofilm reactor and a membrane bioreactor, which combines suspended and attached biomass, was analysed. This system combines suspended biomass and biofilm processes through the addition of carrier media inside the biological reactor for biofilm growth [13]. This process has been proved to be a very simple and efficient technology in municipal wastewater treatment [14,15]. It was developed on the basis of conventional activated sludge and biofilter processes. In these systems, biomass grows as suspended flocs and biofilm. In the case of biofilm, it adheres and grows attached to small inert elements, usually made of plastic, working as support media for biomass immobilisation. These elements have a lighter density than water and they keep moving inside the reactor. This movement can be driven by aeration in an aerobic reactor or by a mechanical stirrer in an anaerobic or anoxic reactor.

Moving bed biofilm reactors have several advantages when compared to suspended biomass processes: higher biomass concentration, high chemical oxygen demand loading, strong tolerance to loading impact, higher sludge age, lower hydraulic residence times, higher volumetric removal rates, relatively small area requirements and no sludge bulking problem [16]. Moreover, the combination of biofilm reactors with a membrane separation of suspended solids may reduce the effect of membrane fouling caused by high biomass concentrations inside membrane bioreactors [17,18]. When they are compared to other kinds of biofilm processes, moving bed biofilm reactors present very good mixing conditions, resulting in efficient mass transfer and the elimination of the risks of clogging of the media with biomass or other solids. In this way, they have the capacity to handle high loads of particulate matter [19].

Additionally, the increase of the sludge age in the system leads to the creation of a favourable environment for the growth of nitrifying bacteria [20], which is also supported by biomass immobilisation as a biofilm allowing to maintain slow-growing organisms in the system. Nitrification and denitrification are two of the most important processes used in wastewater treatment and they have been used successfully in biofilm reactors [4]. In general, *Nitrosomonas* and *Nitrobacter* are assumed to be responsible for nitrification in wastewater, while denitrification is achieved by denitrifying organisms, although an organic carbon source is required [4,21,22].

In the last few years, many studies have been carried out on these systems, with the goals of assessing process performance and the interaction between suspended and biofilm growth, comparing different biofilm carriers. In this way, interesting results have been obtained showing the effectiveness of these systems for organic matter and nitrogen removal. In this sense, operational results showed both a purification improvement of organic matter and ammonia and the existence of simultaneous denitrification [23,24].

However, moving bed biofilm reactor processes are relatively novel from the point of view of the kinetics and there are some uncertainties regarding the kinetic performance of these systems.