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Performance of submerged oscillatory membrane photoreactor for water treatment

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ABSTRACT

Enhancement of a slurry hybrid membrane photoreactor (MPR) is investigated using an oscillatory microfiltration membrane and ZnO photocatalyst. The investigation involved the photocatalytic decolourization of methylene blue (MB) dye as a model pollutant compound. The effect of the operating parameters on the dye decolourization and its relation to the membrane-catalyst retention characteristics is studied. The results showed that application of oscillatory motion resulted in minimizing catalyst particles deposition on the membrane which increased its concentration in suspension and led to higher decolourization rates. Such effect was further augmented by the increase in membrane permeate flux due to the lower hydraulic resistance caused by catalyst deposition on the membrane surface. Furthermore, use of ZnO as photocatalyst has the potential of providing several advantages in terms of high UV absorbance as well as alleviating the need for using oxygen scavenging for charge separation. The latter when combined with the relatively low transmembrane pressure drop requirements by microfiltration (MF) membranes, can result in reducing the overall process energy demand. Such effects suggest that the proposed configuration may be considered as an effective approach for augmenting the productivity of membrane photoreactor for water and wastewater treatment applications.

1. Introduction

Advanced oxidation processes using photocatalytic reactors have been proven as an effective and viable option for degradation of organic and toxic pollutants in water and wastewater treatment applications. In photocatalytic processes, the catalyst can either be suspended in the reaction mixture or immobilized on a carrier material [1,2]. The latter have the intrinsic advantage of not requiring catalyst recovery operation, but they have some drawbacks such as reduced processing capacity due to mass transfer limitations, low specific surface area and low UV utilization efficiency [3]. Suspended catalyst reactors on the other hand have higher mass transfer area and reaction rate for the same catalyst quantity, but are challenged by the inherent problem of the need to separate the catalyst particles from the treated water [4–7]. To achieve the benefits of both configuration and minimize their limitations, the concept of confining or recycling the photocatalyst within the treatment unit using a membrane was proposed. Although such approach can resolve the slurry separation limitation, it suffers from the membrane fouling problems, which remains the primary hindrance for its large scale applications due its negative impact on permeate flux, energy consumption, and the membranes lifespan [8].

Membrane fouling in a photoreactor can be due to either the particles present in the parent water feed, or the photocatalyst particles itself. The contribution of the latter can be significant, particularly at low cross-flow velocities and high transmembrane pressure (TMP) where large amount of the catalyst loading can deposit on the membrane surface leading to formation of a dense layer [9]. Such deposit not only results in higher flow resistance and TMP pumping energy, but also diminishes the effective catalyst concentration in suspension, which reduces the photocatalytic reaction rate [10]. Furthermore, the deposited catalyst particles can be regarded as an origin of further membrane fouling through which other foulants can play different roles [11,12].

To alleviate fouling in a membrane photoreactor (MPR), various strategies may be used and an excellent review of the subject has been published recently that discusses the characteristic of the different techniques [13]. Among those are, self-cleaning process (photocatalytic oxidation), feed pretreatment, membrane modification, aeration, application of electric field, optimization of operating parameters, and membrane cleaning.

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Nomenclature

a	Amplitude of oscillation (m)
c	Concentration (mole/m^3)
f	Frequency of oscillations (Hz)
J	Filtration flux (m^3/m^2 s or LMH)
J_o	Initial flux (m^3/m^2.s or LMH)
J_{qs}	Quasi-Steady-state flux (m^3/m^2 s or LMH)
k	Rate constant (time^{-1})
k_{app}	Apparent reaction rate constant (time^{-1})
k_i	Constant in the blocking model (−)
K	Adsorption coefficient (m^3/mol)
L_m	Length of the membrane surface (m)
n	Blocking models parameter (−)
Q	Excess particle concentration (−)
ΔP	Transmembrane pressure drop-TMP (N/m^2)
r	Reaction rate (mole/m^3 s)
r_p	Particle radius (m)
R	Overall filtration resistance to the flow of liquid (1/m)
t	Time (s)
y	Distance perpendicular to the surface of the membrane (m)

Greek Symbols

γ	Shear rate (1/s)
φ_b	Solids volume fraction of the bulk liquid (−)
μ	Dynamic viscosity of the suspension (kg/m s)
ν	Kinematic viscosity of the suspension (m^2/s)
ω	Angular frequency (1/s)

Abbreviations

LMH	L m^{-2} h^{-1}
MB	Methylene blue
MPR	Membrane photoreactor
TMP	Transmembrane pressure

In this work, a hybrid slurry MPR configuration is proposed with the objective of maximizing the process productivity and minimizing its specific energy and processing costs. The proposed design is based on using commercially available ZnO as a photocatalyst and an oscillatory low TMP submerged microfiltration (MF) membrane to separate the catalyst from the permeate. The proposed arrangement provides several advantages. First, application of oscillatory motion has proven very effective in minimizing particles deposition on the membrane surface [14,15]. This enhances the membrane flux and reduces other adverse fouling impacts on the membrane lifespan. Second, minimizing the catalyst particles deposition on the membrane surface increases its concentration in the suspension which enhances the effectiveness the photocatalytic process. Third, and by controlling the oscillation intensity, it becomes possible to decouple the feed flow from the shear rate necessary for the removal of the deposit layer from the membrane surface, which provides another degree of freedom to control the reactor residence time. Fourth, using MF membrane compared to for example ultra or nano filtration membranes, offers many advantages in terms of lower material cost as well as TMP pumping energy, which represent major cost elements in most membrane processes.

This contribution presents the results of studying the performance of the proposed oscillatory MPR using Methylene Blue (MB) dye as a model pollutant and ZnO catalyst. The latter has demonstrated excellent photocatalytic properties due to its high UV absorbance and unique crystalline structure that works as scavenging sites of the photo-generated electrons, which enhances charge separation and alleviate the need for using oxygen for that purpose [16–18]. In the first part of the paper, the results of initial batch studies of the dye photocatalytic decolourization are presented. The second part includes results and discussion of the performance of the oscillatory MPR.

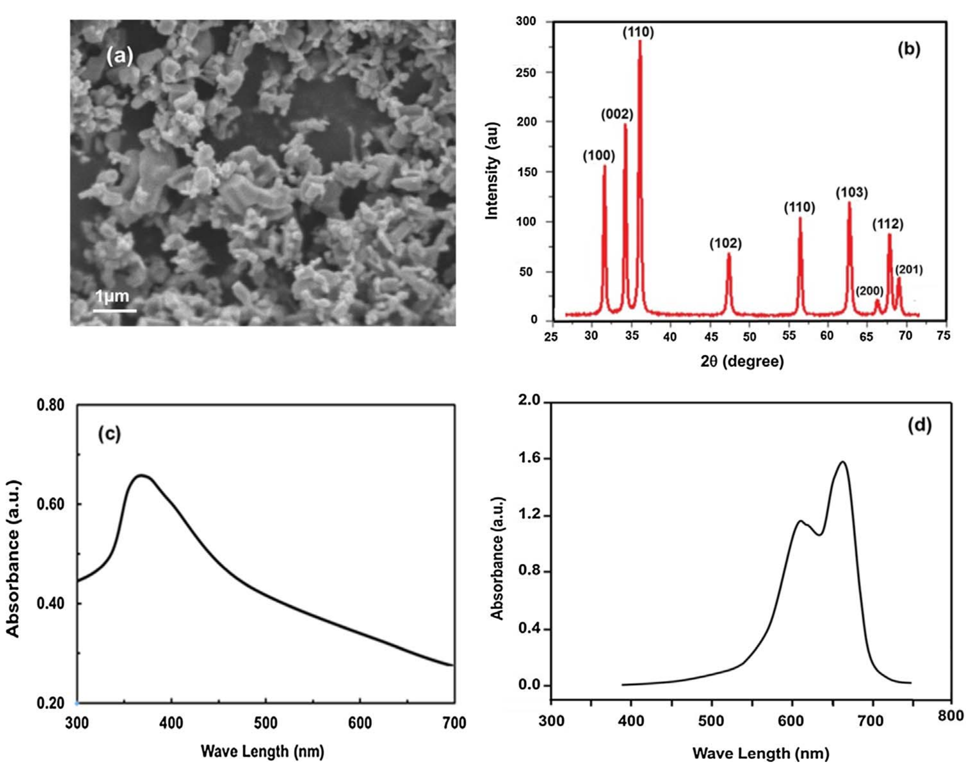

Fig. 1. Materials Characterization. ZnO: FESEM image (a), XRD patterns. UV/VIS absorbance: ZnO (c), and MB (d).