DESIGN OF A MICRO-CHANNEL REACTOR FOR INTENSIFICATION IN HETEROGENEOUS PHOTOCATALYSIS

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Summary

Photocatalytic micro-channel reactor was built by using stereolithography process. A reactor with a micro-channel as a support of TiO_2 photocatalyst was designed in order to reduce dimensions while improving the efficiency. Photocatalytic activity of the micro-reactor at various flow rates was evaluated by the inlet and outlet concentrations of salicylic acid as a model of pollutant. Influence of the initial pollutant concentration, the irradiation intensity on the rate of degradation of the pollutant was studied. A model with the kinetic parameters for the given support geometry was applied to reactor design and scale-up.

Keywords

Design of catalysts; Process intensification; micro reactors.

Introduction

Among photochemical treatments, photocatalysis is efficient with the advantage of oxidizing most contaminants of water until their complete destruction (mineralization) with no selective transfer of the pollutants and products on the surface of adsorbent. It uses the inexpensive and available UV-A light as sources of irradiation as well as the water and oxygen as oxidizing agents (Hermann et al, 1999). Among the possible solutions for intensification of photocatalytic reactions there is the use of micro-reactors (Van Gerven et al, 2007). The design and manufacture of micro-reactors by stereolithography process, authorizes the fabrication of complex forms with a great flexibility. The main objective of the research has concerned the design and manufacture of a catalytic support whose characteristics are: the largest ratio of surface area to volume in order to obtain a great contact of the pollutant with the catalyst, the most important homogeneous irradiation on the whole surface of the structure. Another research has focused on the study of the influence of geometrical characteristics of the catalytic support (depth, width, length) on the photocatalytic activity. When we reduce the dimensions of the reactor, the usual limit conditions, the models and the correlations of the hydrodynamics laws do not still apply on channel flows. The Microsystems have typically characteristic dimensions between micron and millimeter. In that case, physical phenomena cannot be any more neglected in the study of the internal flows of fluid because the report area / volume is sharply important in the Microsystems.

Experimental setup

The micro-channel reactor has been made in epoxy resin (SI 30) by a self-made stereolithography apparatus using a UV Nd-YAG laser. The main characteristics of three micro reactors are described in the following Table 1. All of them are with the same length L of 70 mm and a channel height of 0.5 mm.

Table 1
Geometrical characteristic of micro-reactors.

Name	*Width w(mm)*	*Height h(mm)*	*Volume (mm^3)*	*Surface Spec. κ(mm^{-1})*
R5	1	0.5	35	4.0
R1	1.5	0.5	52.5	3.3
R6	2	0.5	70	3.0

Other authors (Ray and Beenackers, 1998) identified the illuminated specific surface area κ within the reactor as an important parameter: $\kappa = (2h+w)/hw$

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The surface of the channel was coated with TiO2 thin film (3 mg/cm^2) by filling it with an acidic aqueous suspension of TiO2. The experimental setup used for the photocatalytic tests is shown on Figure 1. A flow of polluted water is injected with a syringe at a low flow rate into the micro-structured reactor and irradiated with an UV fluorescent lamp at a constant intensity of 1.5 mW/cm^2.

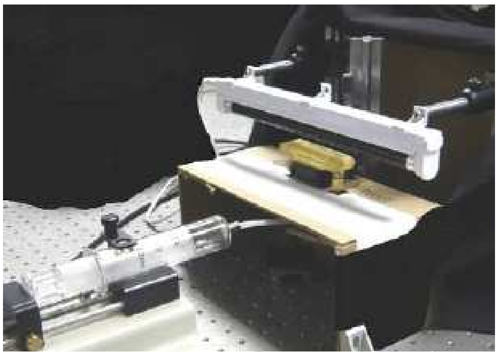

Fig. 1. Experimental setup for Photocatalytic reaction with a micro-reactor and syringe used for the injection of the aqueous salicylic acid solution.

In order to validate the micro-structured reactor in a photocatalytic reaction, salicylic acid (SA) has been chosen as model molecule, previously studied in the laboratory (Ould-Mame et al., 2000). Its concentration after photoreaction was followed by HPLC with conditions already described. The column effluent was monitored and the detector adjusted at λ = 295 nm.

Results and discussion

Effect of the contact time

The effect of contact time on salicylic acid (SA) outlet concentrations was investigated during several minutes. Figure 2 shows that pollutant conversion decreases with the flow rate Q. A high flow rate corresponds to a short contact time with the catalyst and therefore a low conversion ratio.

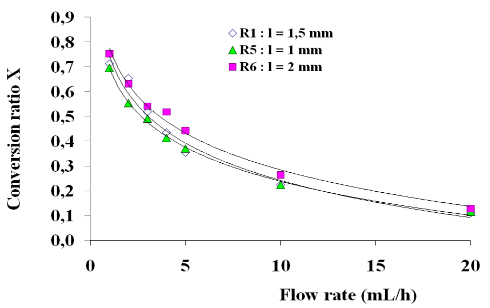

Fig. 2. Effect of channel width on the conversion ratio of salicylic Acid in function of flow rate ; Intensity of irradiation = 1.5 mW/cm^2.

It has to be noticed that, the effect of the contact time of reactant was studied by varying the volumetric flow rate with a constant concentration of 10 mg/l of SA. Figure 2 shows that pollutant outlet concentration decreases first rapidly as the flow rate is low which corresponds of a high contact time. There is a slight effect of the channel width on the conversion ratio.

Effect of the pressure drop

The main goal of this study is to analyze the role of hydrodynamics on the performance of micro-reactor. The concept of the pressure drop results from viscous constraints which act on the walls of the micro-reactor. For one section of some shape (not circular) the tangential constraint is not constant any more on the perimeter of the micro-channel. The viscous flow of the liquid is incompressible with a constant viscosity. This flow can be described by three conservation equations of mass, movement and energy. The pressure drop ΔP is thus calculated in function of the characteristic dimensions h/l of the micro-reactor:

$$\Delta P = \frac{Po}{8}\mu Q\frac{(l+2h)^2}{l^3h^3}L$$

Where Po is the number of Poiseuille. The pressure drop ΔP is a linear function of the flow rate Q. Thus a relation between the pressure drop and the conversion ratio can be deduced.

With the assumption of a Langmuir-Hinshelwood model and the introduction of the apparent rate constant k and apparent adsorption constant K, we have calculated the variation of the conversion ratio X in function of pressure drop. There is a high decrease of the conversion ratio with the pressure drop.

References

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