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Influence of inlet positions on the flow behavior inside a photoreactor using radiotracers and colored tracer investigations

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Abstract

The influence of the inlet positions on the flow behavior inside a photoreactor has been studied using colored tracer and radiotracer investigations. The photoreactor for water disinfection is a tubular reactor inside which UV emitting lamps are placed. The key to its good performance is a combination of optimum irradiation dose and fluid residence time distributions (RTD). The inlet system is one of the better possibilities of controling the fluid RTD. Three configurations have been tested. In the first step, colored tracer experiments help us to raise the mean trends of the flow behavior for the different configurations. When the inlet is located at the central bottom of the reactor, the flow is closed to a perfect mixing whereas lateral inlets lead to a plug flow with axial dispersion behavior. RTD measurements using radiotracer was carried out in a wide range of flowrates. The axial dispersion coefficient increases linearly with the Reynolds number. It is lower when the lateral inlet is divided in three inlets uniformly distributed around the bottom of the reactor. This paper shows the usefulness of radioactive isotopes as tracers in the field of wastewater treatment.

Keywords: Photoreactor; Residence time distribution; Radioactive isotope; Tracers; Water treatment

1. Introduction

UV radiation is quite effective in pathogen inactivation and is even more effective against viral organisms than chlorine (Qualls and Johnson, 1985), with a broad spectrum of effluents. It is a relatively simple method that does not require stocking, transport and chemical manipulations, qualified personnel to deal with it, and does not generate residues. Besides, the risk of an overdose does not impact receiving watercourses (USEPA, 1986).

Research on this technique has been resumed (Oliver and Cosgrove, 1975). Initial results on fecal coliform inactivation in pilot scale proved successful, and this prompted other investigators to apply the technology to real-scale flow (Scheible and Bassell, 1981).

The bactericide action is related to the UV absorption by DNA molecules and the consequent formation of pyrimidines (thymine and cytosine) dimers, the maximum yield being reached at the 260 nm wavelength (USEPA, 1986). These dimers inhibit DNA replication, leading to the death of the cell. In the case of viruses, inactivation stems from uracil, instead of thymine, dimerization. The main sources of UV radiation at the above wavelength are commercial low-pressure mercury lamps whose energy peak is at 254 nm (about 85%), and their quartz bulbs allow the transmission of 93% of the intensity. New lamps are being made available, such as the low pressure and high output (LPHO), which raise the power and lower the cost (Alves, 2003). Experiments conducted by Liu et al. (2002) have shown that the UV doses typically used in sewage disinfection (less than 500 mW s/cm^2) do not result in byproduct formation.

To illustrate the efficiency of the method and the broad spectrum of applications, Table 1 summarizes the results from several studies related to secondary and tertiary effluent disinfection by means of UV radiation incident upon total and fecal coliforms, as well as *Escherichia coli* indicators. The last line in the table gives results obtained with the industrial reactor presented in this paper.

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Table 1
Results from UV disinfection of total coliforms, fecal coliforms and *E. coli*

Reference	Dosis (mW s/cm^2)	Suspended solids (mg/l)	Transmittance (%)	Efficiency (log)	Effluent
Andreadakis et al. (1999)	30	20	38	2.3	Secondary
Castro Silva (2001)	41	64	—	4.7	UASB reactor
Castro Silva (2001)	21	46	—	4.9	Percolating biologic filter
Gonçalves et al. (2001b)	59	26	41	4.5	Submersed aerated biofilter
Gonçalves et al. (2001b)	21	16	39	3.8	Tertiary filter
Janex et al. (1998)	37	17–85	48–60	3.0	Secondary
Qualls and Johnson (1985)	26	32	—	3.1	Activated sludge
Savoye et al. (2001)	25	81	45	2.3	Activated sludge
Alves (2003)	22	75	38	3.1	UASB reactor
	22	19	56	3.3	Percolating biologic filter
	22	102	18	2.6	Maturation pond

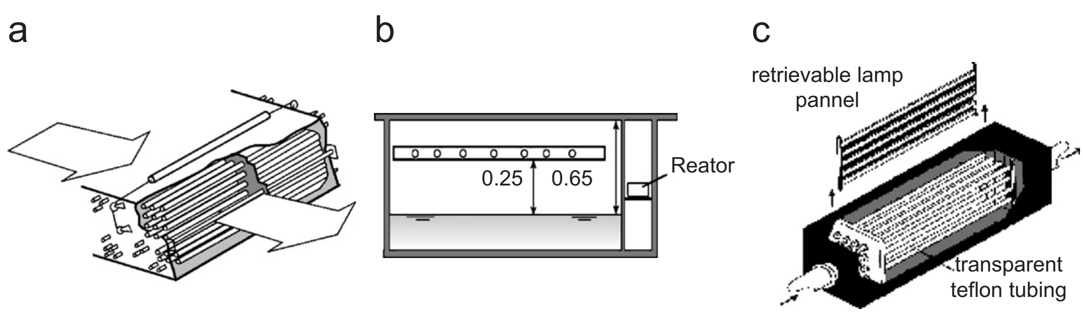

Fig. 1. Sketch of the three main photoreactor types (Chernicharo et al., 2001).

Photocatalytic reactors have also been intensively studied. They contain semi-conductor catalysts such as TiO_2 that efficiently generate the highly reactive $^{\bullet}OH$ free radicals, which are highly toxic towards microorganisms and can drive oxidation processes suitable for the abatement of organic contaminants in water. Some of these reactors make profit of sunlight for this purpose; use is made of the near-UV part of the solar spectrum ($\lambda < 380$ nm) to photoexcite the catalyst (Malato et al., 2002). Working with a pilot-scale-fluidized photocatalytic reactor handling 46 l/min, Kabir et al. (2003) have found that it is capable of degrading 84% of *E. coli* within 80 min compared with 77.3% by using UV only.

However, these photocatalytic processes are highly influenced by the variations of parameters such as light intensity, catalyst concentration, initial bacterial concentration, and the presence of organic matter. These parameters must be carefully adjusted in order to optimize and stabilize the inactivation yield, and this is a handicap in the case of simple treatment plants devised to be operated by non-specialized personnel.

Water disinfection can be carried in different photoreactors (Chernicharo et al., 2001), as shown in Fig. 1:

(a) Lamps placed inside the liquid.
(b) Lamps backed with reflectors placed above the liquid.
(c) Lamps external to the fluid that flows inside transparent tubing.

Photoreactors designed for wastewater disinfection often consist of a set of lamps mounted inside an encased space, in contact with the effluent, which flows either parallel or transversally to them. Besides the characterization of the disinfection kinetics, the influence of suspended solids and the operational costs in such photoreactors, a basic requirement is the evaluation of its hydrodynamic behavior. Due to its decisive influence on the reaction yield, this last item is still a theme for ongoing investigation and optimization. The intensity of the radiation inside the reactor decreases exponentially with the distance from the lamps according to Beer's law. Hence under ideal conditions, plug flow should be attained, assisted by a satisfactory amount of radial turbulence, so that each fluid element would receive the same radiation dose during its transit through the reactor. Dead zones and preferential paths should be avoided since they result in a low efficiency of the power of the lamps, which represents the largest component of the UV disinfection implantation and operation costs. The hydrodynamic behavior of different kinds of photoreactors has been previously studied by several investigators (Kreft et al., 1986; Qualls and Johnson, 1985; Gonçalves et al., 2001a; Legentilhomme and Legrand, 1995; Pruvost et al., 2000;