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Influence of operating parameters on photocatalytic oxidation treatment efficiency: contact time investigation

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SUMMARY

The photocatalytic oxidation (PCO) of toluene was performed in a dynamic loop reactor with control of key process parameters: UV-light intensity and air flow rate. The initial concentration of toluene was fixed at 800 ppb. The relative humidity was set at 50% (i.e. 13 000 ppm) to be close to real indoor air conditions. Two photocatalytic media geometries were used in a way to optimize the contact time. Flat and pleated geometry were studied. CFD simulations were performed with ANSYS-CFX® computational fluid software. Influence of the contact time was assessed and related to the geometry of the material. The local contact time was evaluated to be 9 times higher regarding the pleated geometry. This latter impacts the global PCO efficiency; it plays a role in the contact time between the effluent and the photocatalytic material.

PRACTICAL IMPLICATIONS

This work aims at the evaluation of the filter geometry influence on the efficiency of photocatalytic oxidation treatment. The geometry and contact time are directly related and are influencing parameters in the elimination of VOCs.

KEYWORDS

VOCs, ppb levels, Operating conditions, Contact time influence

1 INTRODUCTION

Indoor air pollution is a public health issue of great concern. People spend most of their lifetime in enclosed places, where air quality is impacted by several forms of pollution. Volatile organic compounds (VOCs) are the most important gaseous pollutants present in indoor air and aromatic hydrocarbons have been identified as major compounds (Gallego et al, 2009). Among processes available for air treatment, photocatalytic oxidation (PCO) can be used to improve indoor air quality. Although many studies on PCO of VOCs were published, no extensive investigation of the influence of process parameters on PCO has been made yet.

The specific aim of this work is to assess the impact of photocatalytic media geometry on the contact time during the PCO of toluene. To do so, toluene was chosen as typical aromatic pollutant. Experiments were performed under conditions close to real indoor atmospheres. Process parameters such as UV light intensity and air flow rate were taken into account. In parallel, the contact time between the fluid and the photocatalyst media as a function of global flow rate was estimated by performing CFD simulations.

2 MATERIALS/METHODS

A 420 L multi-pass dynamic photocatalytic pilot was used to carry out the PCO experiments. It is represented Figure 1. It has also been described in previous articles (Maudhuit et al, 2011).

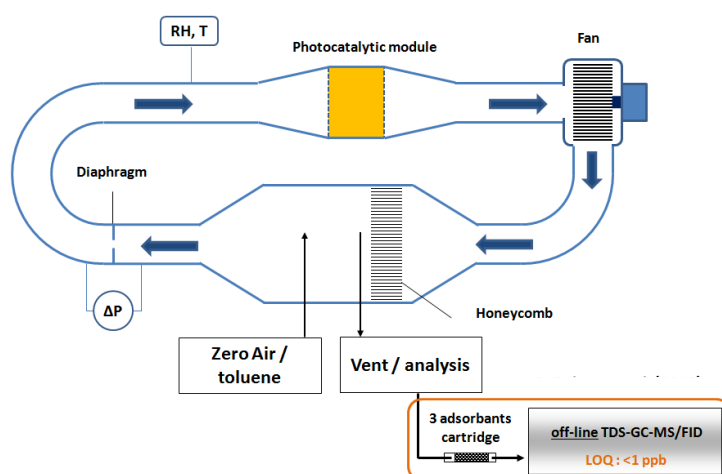


Figure 1. Schematic representation of the multi-pass dynamic photocatalytic pilot.

The initial concentration of toluene was fixed at 800 ppb. The relative humidity was set at 50% (i.e. 13 000 ppm) to be close to real indoor air conditions. The photocatalytic media was supplied by Ahlström Paper Group. It is constituted of a thin fibrous support composed of a mixture of cellulose, polyester and polyamide and coated with P25 TiO₂ in a SiO₂ binder. The analytical methods were adapted to the level of concentrations tested in this work (Debono et al, 2011). Two geometries were used for the media configuration, a flat geometry and a pleated geometry. The flat media was positioned orthogonally to the flow and the pleated one was positioned as presented Figure 2.

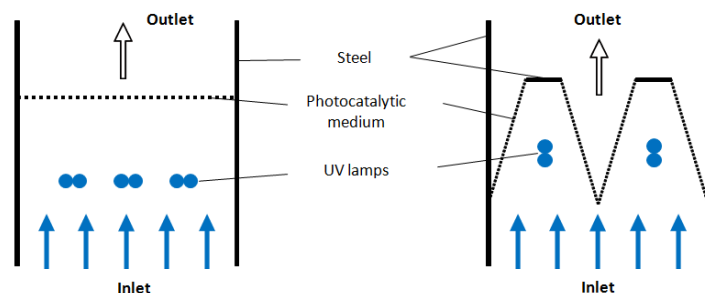


Figure 2. Top-view geometry of the photocatalytic media used in flat and pleated configurations.

Global flow rate was set to $28.8 \text{ Nm}^3 \cdot \text{h}^{-1}$, average photon flux (UV-B, $\lambda = 365 \text{ nm}$) on media surface was set to $0.5 \text{ mW} \cdot \text{cm}^{-2}$, and the toluene concentration is homogenized in the whole reactor prior to all experiments.

CFD simulation was performed with ANSYS-CFX® computational fluid software. The calculations use the finite volume method on which the software is based.

3 RESULTS AND DISCUSSION

Figure 3 shows the kinetic curves of toluene PCO degradation obtained with flat and pleated media configurations.

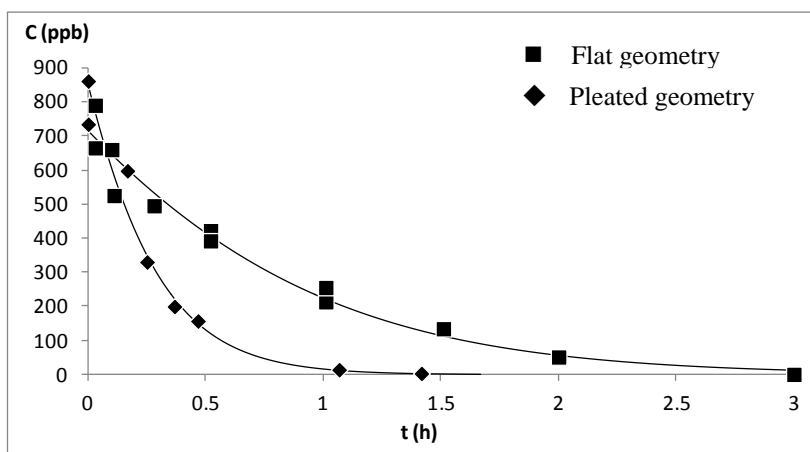


Figure 3. Kinetic curves of toluene PCO degradation obtained in the dynamic reactor, with flat and pleated media. $C_0 = 800$ ppb, $Q = 28.8 \text{ Nm}^3 \cdot \text{h}^{-1}$, $\text{RH} = 50\%$, $I = 0.5 \text{ mW} \cdot \text{cm}^{-2}$.

In this case, the toluene PCO is more efficient in the reactor with pleated media than flat media configuration. Three main reasons may account for this efficiency increase: (i) the surface and thus the quantity of catalyst is higher, (ii) the contact time is longer and (iii) the quantum yield is better optimized.

Apparent first order kinetic constants were calculated taking into account the photocatalytic media surface. It appears that the kinetic constant is almost twice higher in the pleated geometry. To deepen the influence of the contact time on the PCO efficiency, the CFD simulation has permitted to assess the behaviour of the velocity field of air stream through the reactor. Figure 4 shows the velocity field simulation of air stream through the reactor module with the pleated media.

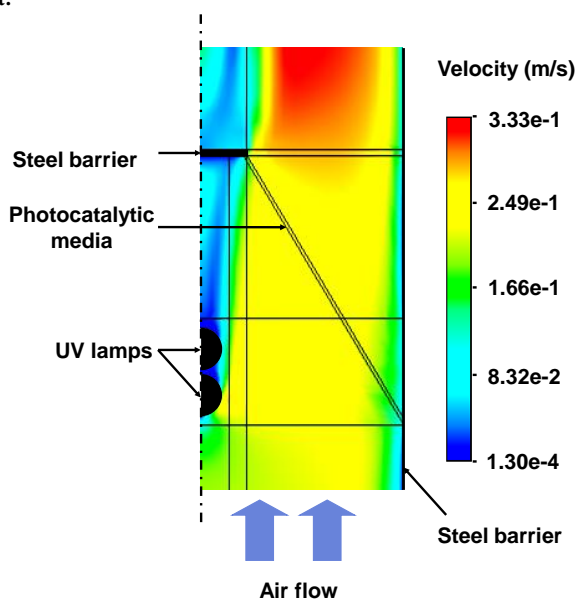


Figure 4. CFD velocity field simulation on reactor geometry. The average flow velocity is $0.2 \text{ m} \cdot \text{s}^{-1}$.

Simulation results show a good global homogeneity of the fluid distribution at the media surface. The global superficial velocities are around $0.2 \text{ m} \cdot \text{s}^{-1}$.

In addition, it has been thought necessary to assess the behaviour at more local scale. If the overall flow velocity at global scale is assessed to be $0.2 \text{ m}\cdot\text{s}^{-1}$, it may be different when looking at smaller scale. To proceed, the modeling of the photocatalytic medium was made as represented in Figure 5. The material was assumed to be represented as a composite material, taking into account that its fibers are separated by regularly spaced holes. The elementary mesh was then made of 3 homogeneous distinct material parts: the hole itself, a non permeable solid area, and an intermediate permeable area.

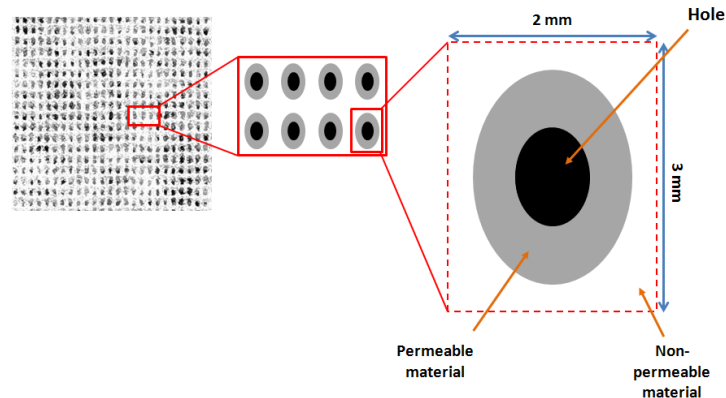


Figure 5. Schematic representation of the modelling of the photocatalytic media.

Starting with several initial assumptions, CFD simulations calculation permitted to describe the gases stream lines going through the media. The velocity of gases crossing the surface in the permeable part decreases, whereas the gases crossing the holes are accelerated. It also enabled to calculate in the permeable area the contact time between the fluid and the photocatalytic material.

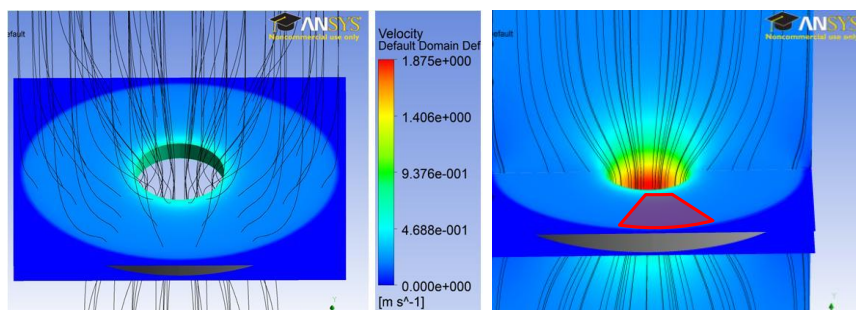


Figure 6. 3D representation of the gases stream lines (left) and the velocity field in a section perpendicular to the hole (right).

The local contact time found in this case for the flat geometry was equal to 0.8 ms as it was calculated to be 7.1 ms for the pleated geometry. The local contact time was then 8.9 times higher. It is evidenced that the local decrease of gases velocity on media surface is induced by the geometry. This decrease is proportional to a local contact time increase. Consequently, this phenomenon can lead to an additional noticeable improvement of global PCO process efficiency.

5 CONCLUSIONS

The toluene PCO was performed in a dynamic multi-pass reactor with control of key process parameters: UV-light intensity and air flow rate. A flat and a pleated geometry were used for photocatalytic media configuration. PCO was proved to be more efficient in the pleated

configuration. Local increases of the contact time were evidenced from CFD simulation. These results show the possible positive influence of the media geometry on the global efficiency of photocatalytic processes. To better assess the advantage of pleated filters regarding the contact time, further investigations on geometry are currently performed. In each case, the global and local calculation of the air velocity and the resulting contact time are evaluated. Depending on the general geometry of the media and the distance between the photocatalytic material and the irradiation sources, the distribution of the light intensity received on the media may be significantly different. For the same average light intensity received on the photocatalytic media, a modification of the heterogeneous intensity distribution can also have a strong influence on the global efficiency of the PCO. Additional experiments tend to assess the influence of the heterogeneity of the light intensity distribution on the photocatalytic media.

ACKNOWLEDGEMENT

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