Journal of Environmental Management 155 (2015) 136–144

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Construction of a photocatalytic de-polluting field site in the Leopold II tunnel in Brussels

E. Boonen [a, *], V. Akylas [b], F. Barmpas [b], A. Boréave [c], L. Bottalico [d], M. Cazaunau [e], H. Chen [e], V. Daële [e], T. De Marco [d], J.F. Doussin [f], C. Gaimoz [f], M. Gallus [g], C. George [c], N. Grand [f], B. Grosselin [e], G.L. Guerrini [h], H. Herrmann [i], S. Ifang [g], J. Kleffmann [g], R. Kurtenbach [g], M. Maille [f], G. Manganelli [d], A. Mellouki [e], K. Miet [f], F. Mothes [i], N. Moussiopoulos [b], L. Poulain [i], R. Rabe [i], P. Zapf [f], A. Beeldens [a]

[a] Belgian Road Research Centre (BRRC), Woluwedal 42, 1200 Brussels, Belgium
[b] Laboratory of Heat Transfer and Environmental Engineering (LHTEE), Aristotle University of Thessaloniki, Box 483, GR 54124 Thessaloniki, Greece
[c] Université Lyon 1, CNRS, UMR5256, IRCELYON, Institut de Recherches sur la Catalyse et l'Environnement de Lyon, Villeurbanne, Lyon F 6962, France
[d] CTG Italcementi Group, Via Stezzano 87, 24126 Bergamo, Italy
[e] Institut de Combustion, Aérothermique, Réactivité et Environnement (ICARE), CNRS (UPR 3021)/OSUC, 1C Avenue de la Recherche Scientifique, Orléans, France
[f] LISA, UMR CNRS 7583, Université Paris Est Créteil et Université Paris Diderot, Institut Pierre Simon Laplace, Créteil, France
[g] Physikalische Chemie /FB C, Bergische Universität Wuppertal (BUW), Gaußstr. 20, 42119 Wuppertal, Germany
[h] Italcementi Group, Via Stezzano 87, 24126 Bergamo, Italy
[i] Leibniz-Institut für Troposphärenforschung e.V. (TROPOS), Atmospheric Chemistry Dept., Permoserstraße 15, 04318 Leipzig, Germany

A R T I C L E I N F O

Article history:
Received 17 November 2014
Received in revised form
27 February 2015
Accepted 2 March 2015
Available online 2 April 2015

Keywords:
Photocatalysis
TiO_2
Air purification
Road tunnels
Cementitious coating

A B S T R A C T

Within the framework of the European Life+-funded project *PhotoPAQ (Demonstration of Photocatalytic remediation Processes on Air Quality)*, which was aimed at demonstrating the effectiveness of photocatalytic coating materials on a realistic scale, a photocatalytic de-polluting field site was set up in the Leopold II tunnel in Brussels, Belgium. For that purpose, photocatalytic cementitious materials were applied on the side walls and ceiling of selected test sections inside a one-way tunnel tube. This article presents the configuration of the test sections used and the preparation and implementation of the measuring campaigns inside the Leopold II tunnel. While emphasizing on how to implement measuring campaigns under such conditions, difficulties encountered during these extensive field campaigns are presented and discussed. This included the severe de-activation observed for the investigated material under the polluted tunnel conditions, which was revealed by additional laboratory experiments on photocatalytic samples that were exposed to tunnel air. Finally, recommendations for future applications of photocatalytic building materials inside tunnels are given.

1. Introduction

The de-pollution performance of photocatalytic cement-based materials containing titanium dioxide (TiO_2) has been assessed in numerous studies over the past decade, e.g. (Ângelo et al., 2013; Boonen and Beeldens, 2013; Maggos et al., 2008; Maury-Ramirez et al., 2010; Ohama and Van Gemert, 2011), illustrating their potential for urban pollution control. However, in addition to application on outdoor building façades and road surfaces, these materials – irradiated by artificial UV light to activate them – might also contribute to a significant reduction of air pollution in road tunnels. Although road tunnels in urban areas are usually well ventilated with regular air renewal inside, previous research has shown that they suffer from strongly elevated concentrations of air pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs); these are associated with emissions from road traffic, especially during rush hours (Indrehus and Vassbotn, 2001; Larsson et al., 2007; Vanderstraeten et al., 1991). Moreover, air from tunnels is often ventilated to the ambient atmosphere without effective de-

* Corresponding author.
E-mail address: e.boonen@brrc.be (E. Boonen).

http://dx.doi.org/10.1016/j.jenvman.2015.03.001
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pollution measures and, therefore, contributes to a large extent to air pollution in the areas nearby the ventilation exit. Hence, by cleaning the air inside the tunnel using e.g. TiO_2 photocatalysis technology, not only a significant improvement for tunnel users could be obtained, but also a better air quality for the outside surroundings. So far, to the authors' best knowledge only one study has been conducted on this topic and it was limited to one type of pollutant, i.e. NO_x (Guerrini, 2012).

The European Life + project PhotoPAQ, *Demonstration of Photocatalytic remediation Processes on Air Quality* (PhotoPAQ, 2010–2014), was aimed at demonstrating the usefulness of photocatalytic construction materials for air purification purposes in the urban environment. Eight partners from five different European countries formed the consortium that undertook this project. For the needs of the project, and in view of the aforementioned findings, an extensive three-step field campaign was organized in the Leopold II tunnel in Brussels, Belgium during the period June 2011–January 2013. In particular, two different photocatalytic cementitious coating materials were applied on the side walls and the ceiling of selected sections in the tunnel branch running along the Basilica–Midi axis. The air-purifying surfaces were activated by a dedicated UV lighting system installed inside the tunnel. During the associated field campaigns, the effect of the photocatalytic coatings on air pollution (including NO_x, VOCs, particulate matter, etc.) in the tunnel section was rigorously assessed. In the present article, the construction of the photocatalytic de-polluting field site and the implementation of the field campaigns are elaborated in detail. In addition, the results of some supplementary laboratory experiments are presented; these were performed on photocatalytic samples exposed to tunnel air, in order to investigate possible surface passivation phenomena under the prevailing tunnel conditions. The actual results for NO_x abatement are discussed in more detail elsewhere (Gallus et al., 2015).

2. Setup and requirements for the tunnel field campaigns

Carrying out a monitoring campaign in a tunnel environment has the advantage that local pollution and meteorological conditions are far less variable than in an outdoor environment, thus allowing an easier interpretation of the collected data. For the location of the test site in the tunnel, some general prerequisites had to be met:

- the site should provide the maximum measurable effect of the photocatalytic material;
  - high surface-to-volume ratio of the photocatalytically active test area,
  - high traffic volumes to obtain reasonable pollution levels,
  - limited impact of the tunnel entrances, exits and cross section on the dilution of the air in the test section,
  - limited impact of the ventilation system both on the main environmental parameters like temperature and relative humidity and on the dilution of the tunnel air,
  - limited impact of the traffic flow on the dilution of the tunnel air;
- the aerology of the site should be implementable into numerical models for an assessment of pollution abatement.

In addition to these “experimental” constraints some practical issues had to be considered for the choice of a proper tunnel field site, like the mandatory approval from local authorities to build up a photocatalytic test section, safety issues especially towards the drivers, related to the application of additional UV-lighting to activate the air-purifying products, and, finally, the availability of space to accommodate air monitoring instruments.

2.1. Selection of the field site

Bearing in mind the above-mentioned constraints, the Leopold II tunnel in Brussels (Fig. 1) was selected as the most appropriate field site. The tunnel carries high traffic volumes regularly reaching a few thousands of vehicles per hour (Table 1), which generate a sufficient level of pollutants. Based on the existing air pollution measurements (NO_x and CO) carried out continuously in the tunnel over several years, the section could be described as highly polluted with annual average half-hour concentrations of around 1000 and 400 $\mu g/m^3$ for NO and NO_2, respectively.

The Leopold II tunnel is a two-way tunnel connecting the motorway coming from Ghent and Bruges with the central business district in Brussels. The 2.5 km long city tunnel runs underground along the Basilica–Midi axis, within a densely built urban environment (Fig. 1).

Air quality is currently controlled by a ventilation system through multiple inlets (injectors) and outlets (extractors) over the entire length of the tunnel. As a result, the tunnel is divided into several sections with similar air properties and with lengths varying from 100 to 200 m. The tunnel geometry is highly complex and consists of two segments (one for each direction) separated by a wall, with varying cross-sectional areas along each direction and the presence of several entrances and exits along its length (Fig. 1). However, about 300 m upwind of the selected field site section, at the entrance “Basilique”, the tunnel tubes are separated by regular concrete pillars only, allowing effective mixing of the pollutants from both tunnel tubes. This fact, though, did not influence the field experiments and only caused additional emissions to the tunnel air of the selected site.

A section of about 200 m with a relatively uniform cross section was identified here. This section had the advantage of the presence of a technical room above the tunnel, which allowed accommodation of the large set of scientific instruments to be deployed for air pollution monitoring. Direct connections to the tunnel were provided by holes in the ceiling of the tunnel, in order to position the sampling lines and cables needed for the measurements. The selected section is located between the entrance “Basilique” and the entrance “Sainte-Anne” in the direction to the city centre, as shown in Fig. 1, and it has a surface-to-volume ratio of about 0,4 m^{-1}.

2.2. Field testing strategy in the tunnel

The basic principle of the field campaigns was to compare the air purification effect of photocatalytically active surfaces with that of “normal” non-active surfaces in very similar environments. Furthermore, the study focused on combining two important strategic objectives: testing in realistic circumstances on the one hand, and gathering very precise measurement data on the pollutant concentrations inside the tunnel on the other hand.

Three field testing strategies were extensively discussed:

1) Carrying out measurements *before and after the application* of the material, so that the efficiency of the material can be assessed by comparing the differences in air quality obtained during the two periods. This approach, which has already been chosen in one other study (Guerrini, 2012), has the advantage of being applicable to both indoor and outdoor sites. In addition, it is readily understood by non-scientists and hence easily transferable to decision-makers.

On the other hand, considering the extremely high variability of the concentrations of atmospheric pollutants and/or the meteorological conditions, it would require extremely careful and difficult