Real Scale Demonstration of the Depolluting Capabilities of a Photocatalytic Pavement in a Real Urban Area

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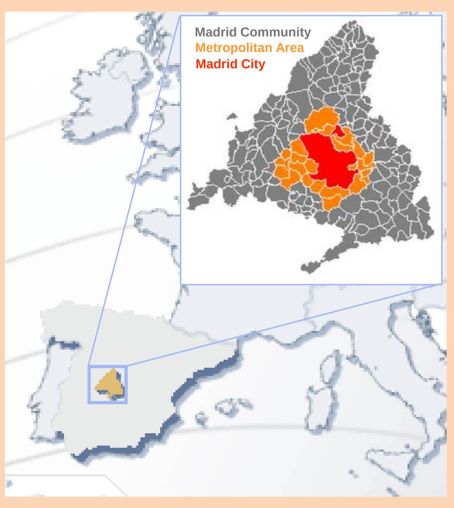
The lessening of pollutants as nitrogen oxides (NO_x) constitutes one of worrying challenges in densely populated areas, where atmospheric pollution problems are mainly caused by road traffic emissions. As a consequence, the development of emerging abatement techniques, as those based on photocatalytic oxidation, is nowadays being fostered. Applying titanium dioxide (TiO_2)-modified coatings or cementitious materials onto the external covering of buildings or roads might be a supplement to conventional technologies, such as catalytic converters fitted on the vehicles, for mitigating air pollution. Nevertheless, although some photocatalytic materials have been deeply studied in laboratory, their efficiency as sink of NO_x at real scale is still matter of debate.

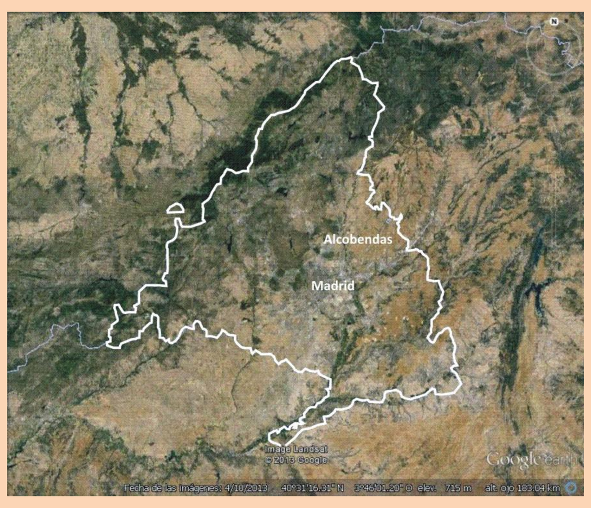
In the framework of LIFE MINOx-STREET European project, a variety of commercial TiO_2 based photocatalytic building materials have been subjected to rigorous laboratory essays in order to study, on one hand, their mechanical and physical properties, operation-induced changes and durability, and, on the other, their photoactivation and air-purifying capacity, chemical and structural properties, and the changes induced by ageing and regeneration processes [1]. Then, the most promising materials have been selected and essayed by means of both outdoor experiments and controlled essays under ambient conditions. The selected photocatalytic coating designed for use on bituminous mixtures has been implemented in a real urban scenario in Alcobendas (Madrid region), in order to assess its effect on the degradation of atmospheric nitrogen compounds.

EXPERIMENTAL SITE

The depolluting capability of the selected photocatalytic coating has been assessed in a real urban scenario of Alcobendas, a municipality of the Region of Madrid. This region is located in the centre of the Iberian Peninsula and counts with the most important metropolitan area in Spain formed by Madrid city and seven other medium towns surrounding the capital. It is well known that NO_x and O_3 are pending air quality problems in this area, being road traffic the main source of pollutants (70% of the anthropogenic emissions in the region). Under episodic conditions, specially in winter, the Madrid metropolitan area is under a big urban plume that affects not only Madrid city and the rest of the metropolitan zone but also important parts of the rural/green surrounding zones.

The place selected for the experiments was the Paseo de la Chopera, a street of Alcobendas with a central strip and moderate traffic.



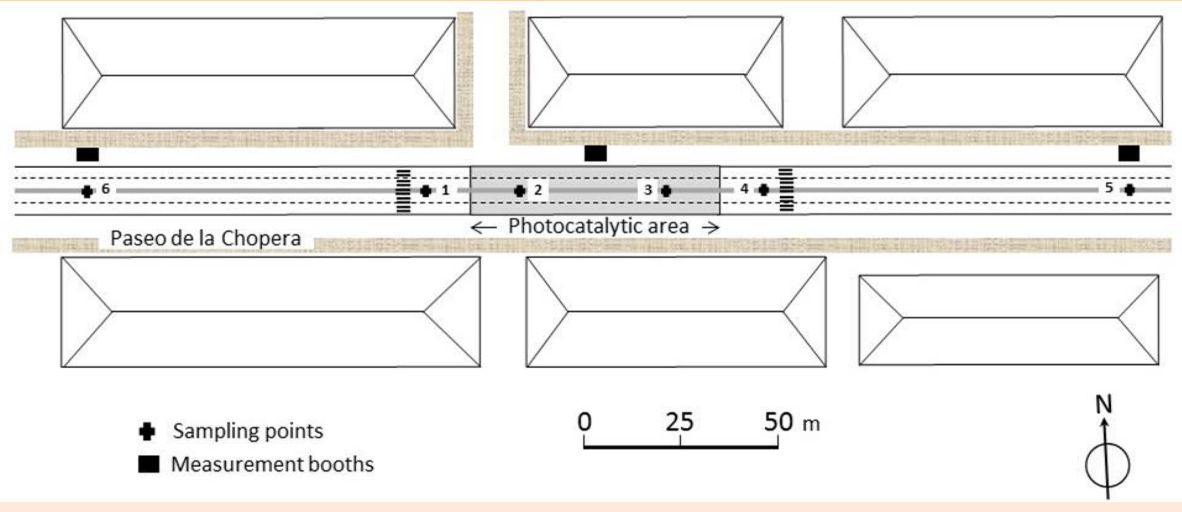


EXPERIMENTAL SET UP

NO_x measurements along Paseo de la Chopera street

Paseo de la Chopera street (Google Earth image)

The photocatalytic coating was implemented in an area of 1000 m² (marked in the image). The street has an east-west orientation that assured enough solar irradiation of the bituminous pavement from 7 to 16 UTC during the experimental campaign (September 15th to October 25th 2015)



Scheme of the experimental set up:
Six PFA sampling lines for continuous measurement of NO, NO_2:
- Sampling points 1 to 4: Thermo Scientific 42i
- Sampling point 5: Thermo Scientific 42i TL
- Sampling point 6: Teledyne API 200 A

Sampling lines and automatic system for NO_x measurements

Sampling lines were deployed for continuous air sampling from points 1 to 6 (see scheme) located in the central strip of the road. Lines were properly protected and buried under the asphalt surface to prevent damage from road traffic. Sampling points were located at 40 cm high and protected with meshed cages anchored to the pavement. The inlet of each line was protected with particulate filters (cut-off diameter of 15 µm).

Three NO_x monitoring systems were placed inside three booths. In the central one an external pump maintained a constant sampling flow for the lines 1 to 4 and every two minutes, in a cyclic base, an automatic switching system selected the sample from one of the lines to be analysed. For each cycle, the NO_x average concentration in each sampling point was determined during the second minute of the correspondent measurement time (2 min).

Implementation of the photocatalytic coating on the road of Paseo de la Chopera

An area of about 1000 m² (corresponding to sixty meters along the road) was covered with the photocatalytic coating by means a distributor truck with a spray bar with nozzles fitted on the back. The application was done after the roadway was cleared of any debris. Traffic was reopened on September, 25th 2015, two days after the product application.

The photocatalytic activity of the selected product over a similar bituminous pavement of Paseo de la Chopera was essayed under the ISO international standard [2] and the NO depolluting efficiency was 45%. After one month from the implementation in Paseo de la Chopera, the efficiency of the photocatalytic coating decreased to 20% due to wear by traffic and aging under ambient conditions.

NO_x and O_3 measurements near Paseo de la Chopera street

Meteorological sensors (air temperature, solar radiation, relative humidity, wind speed and direction) and gas analysers (NO_x, O_3) were deployed at the roof of a building located close to the Paseo de la Chopera, in order to monitor the dynamics and characteristics of the general air mass in the area of interest.

Continuous measurements of NO, NO_2, O_3 and meteorology at 15 m high
NO_x: Teledyne API 200 A
O_3: Teledyne API 400 A
Wind direction: MET ONE 590
Wind speed: MET ONE 591
Temperature and relative humidity: MET ONE 083R
Solar radiation: MET ONE 59

Intensive measurement campaigns

Particulate matter (Ti and NO_3 content)

Ambient air (MOUDI M110R) and deposited on the bituminous pavement (suction device).

Samples were analysed by Inductively Coupled Plasma-Mass Spectrometry, X-ray Fluorescence and Diffraction Spectroscopy and Ionic Chromatography.

Traffic counting with video camera.

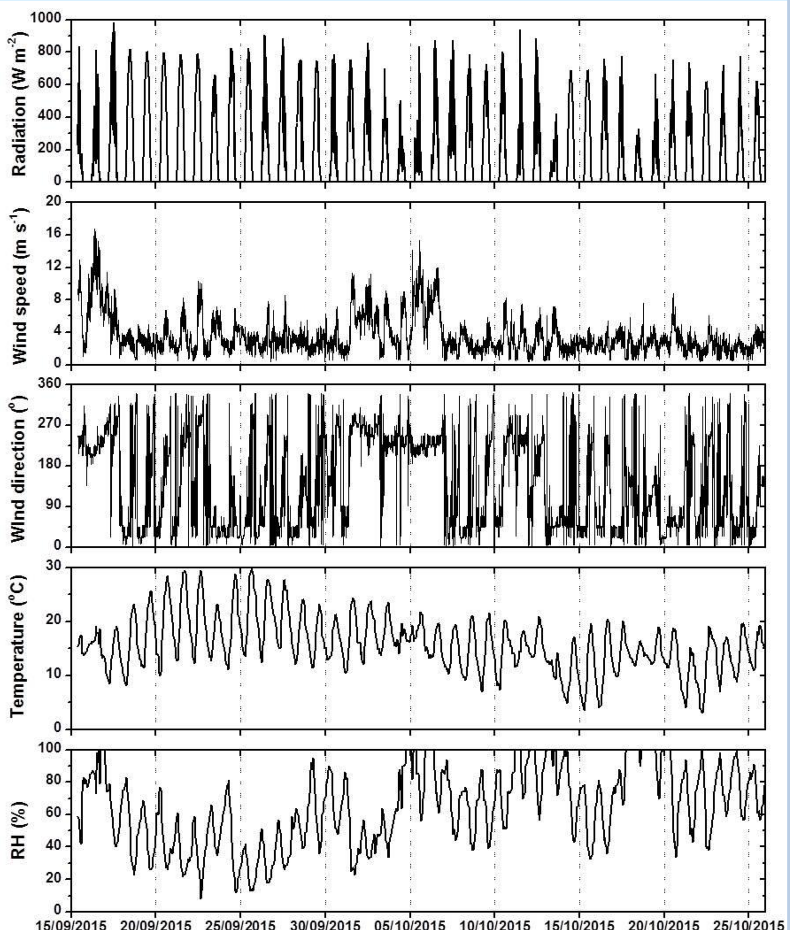
VOC : volatile organic compounds were sampled with Tenax tubes and analysed by Gas Chromatography/Mass Spectrometry.

Lixiviates: nitrate and nitrite measurements. Analysed by Inductively Coupled Plasma-Mass Spectrometry and Ionic Chromatography.

Ultraviolet-A radiation across the street and temperature of facades, sidewalks and bituminous pavement were also characterised.

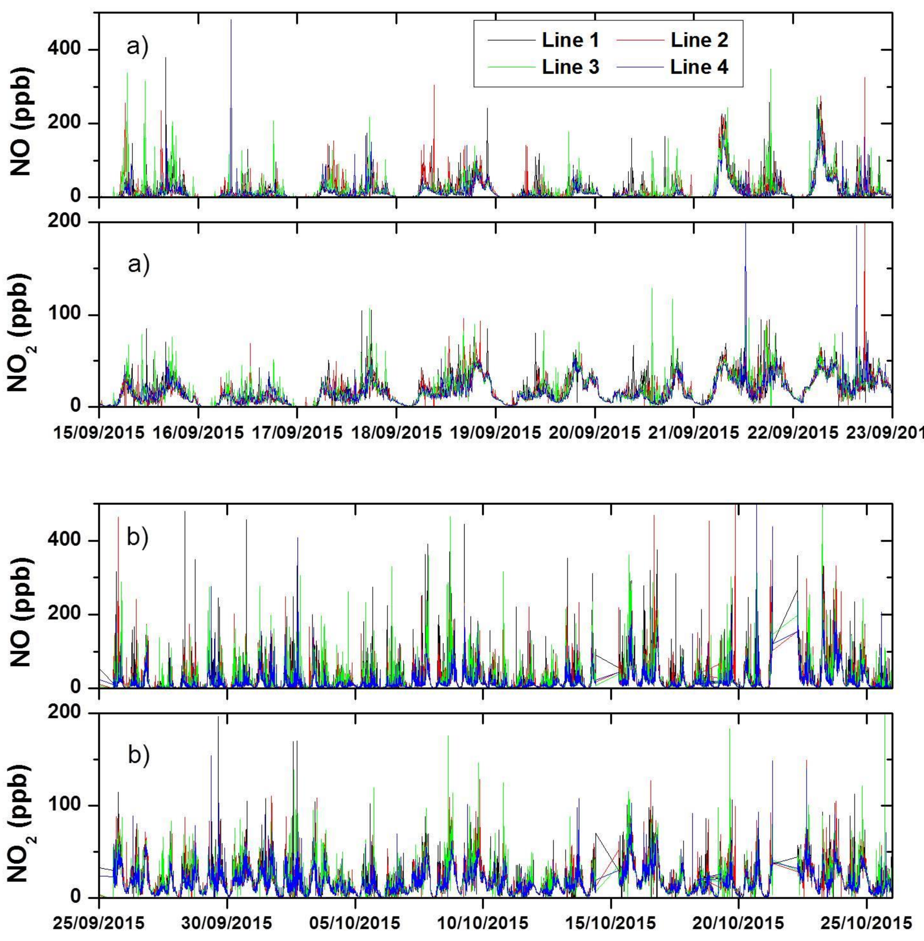
RESULTS

Meteorological variables registered during the campaign (September 15th to October 25th 2015)



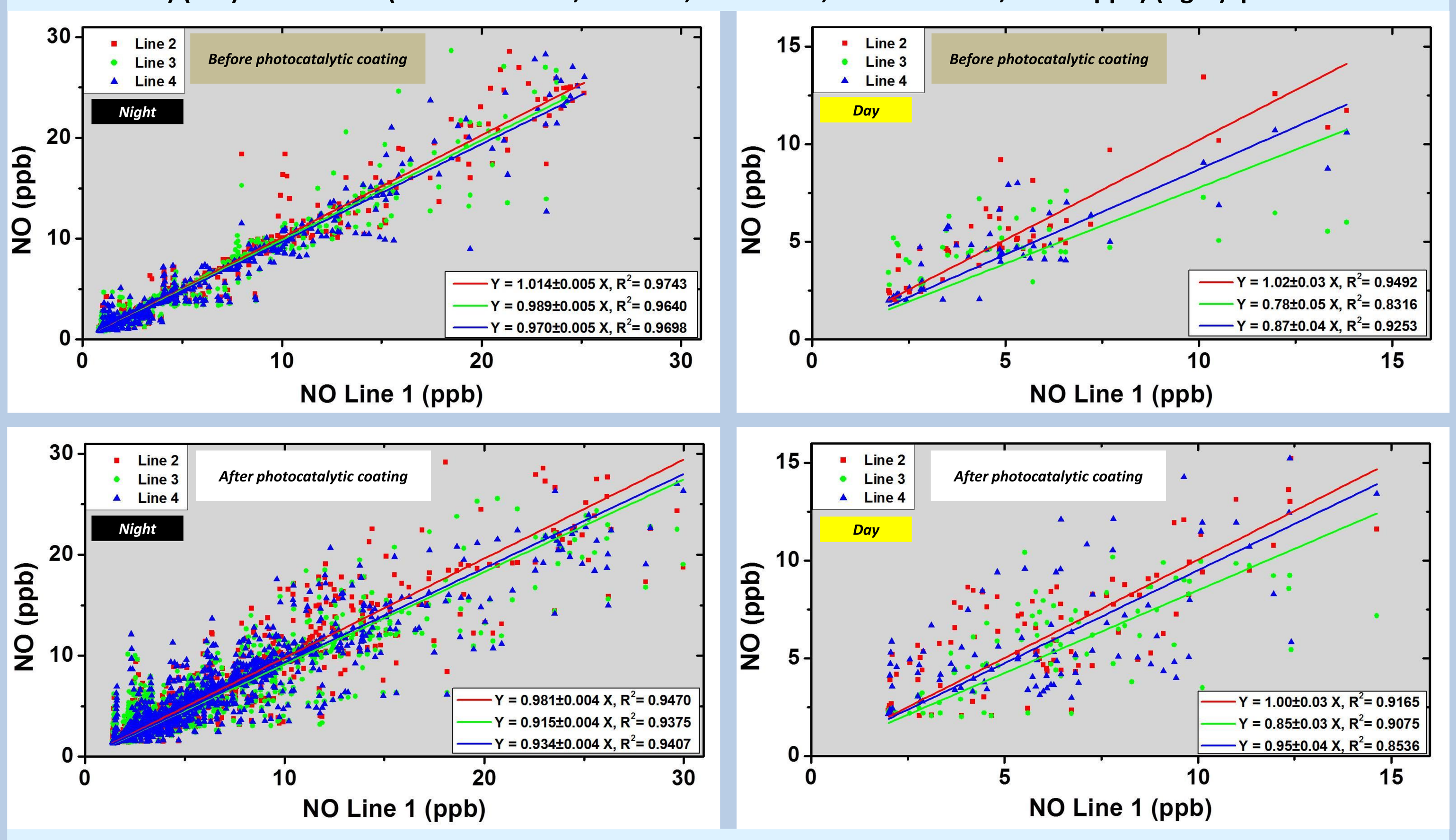
Anticyclonic stagnant conditions occurred during three periods: from September 18th to 22nd, from October 8th to 9th and from October 15th to 16th 2015. Under this kind of meteorological scenarios, the development of a consistent urban plume over the Madrid metropolitan area is very fast (in 1-2 days) and after few days of stability and poor ventilation conditions in the region, NO_2 ambient concentrations exceed frequently the information limit value in different points.

NO_x concentration along the road (sampling lines 1 to 4) during the campaign (September 15th to October 25th 2015)



Maximum NO_x values were registered during traffic rush hours in the morning and in the late afternoon and the concentration profiles correlated quite well with the traffic patterns observed during selected days. The cadence of NO_x measurements one minute averaged allowed to detect the influence of almost every vehicle emissions in this road. It is noticeable the presence of a large amount of peaks superimposed to a NO and NO_2 background level. This fact has hampered the assessment of the NO_x depolluting ability of the photocatalytic road pavement.

NO concentration for lines 2 to 4 vs line 1: without (upper) and with (lower) photocatalytic coating, for nocturnal (00:00 to 04:00 UTC) (left) and diurnal (RAD>400 Wm^{-2}, RH<65%, WS<5 ms^{-1}, 45°<WD<135°, NO<20ppb) (right) periods



The NO concentrations registered from the sampling lines 2, 3 and 4 were correlated against the corresponding values from the line 1.

- *Nocturnal conditions: The correlation values close to unity reflect that the NO content in the four air samples are indistinguishable.*
- *Diurnal conditions: The NO concentration values to be analysed were previously filtered, selecting those periods with favourable meteorological conditions to observe the photocatalytic effect [3,4]. Moreover, in order to avoid the influence of instantaneous NO emissions from traffic, only NO concentration values lower than 20 ppb, not associated to traffic peaks, have been considered. The correlation values obtained to the selected data does not reflect any significant tendency. In absence of those filtering conditions, the NO peaks due to fresh emissions disturb everything, producing very poor linear correlations with lower slope values (around 0.7) (see extended abstract of this work) that are conditioned by the traffic patterns in this road.*
- *The possible photocatalytic remediation effect of NO cannot be observed because the slope values for nocturnal/diurnal periods before and after implementing the photocatalytic coating are actually very similar and without compatible features with any NO sink effect.*

CONCLUSION: The application of a promising photocatalytic product to an important section of a road in Alcobendas (Madrid region) did not produce any improvement effect on ambient NO concentrations, near the surface on the median strip, that could be directly attributed to the presence of such material.

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HARMO'17 — 17th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Budapest, Hungary, 9-12 May 2016

Acknowledgements: This work was supported by LIFE financial instrument of the European Union (LIFE12/ENV/ES/000280)