MEASUREMENT OF ROAD TUNNEL AIR QUALITY - EN 50545-2

[1]Fathi Tarada, [2]B. Vidal, [3]C. Edge, [4]C. Seewald, [5]T. Halbach, [6]R. Hallam
[1]Mosen Ltd, [2]CETU, [3]Dynoptic Systems Ltd, [4]Sick AG,
[5]ORTRAT SL, [6]Codel International Ltd

ABSTRACT

CENELEC working group CLC/TC/TC216/WG5 has been writing a new standard EN 50545-2 for the performance and type testing of air quality sensors for road tunnels, including gas concentration and visibility measurements. This standard will enable tunnel owners and operators to specify robust, accurate measurement devices that can operate with the minimum of maintenance in a harsh, dirty tunnel environment. To that end, independent laboratory and field testing of devices will be specified by the new standard, capturing a range of effects such as span drift, zero drift, the effect of temperature and any effects due to contamination build-ups. The specification of such devices will contribute towards the achievement of a healthy tunnel environment, while keeping the operating costs of tunnel ventilation systems down to reasonable levels.

Keywords: road tunnel, air quality, nitrogen oxide, carbon monoxide, visibility, measurement, device, sensor, instrument, maintenance, CENELEC

1. INTRODUCTION

The measurement of air quality in road tunnels is critical for ensuring the health and well-being of tunnel users (including motorists and maintenance personnel), as well as for the proper control of ventilation systems.

In 2006, the Spanish National Committee of CENELEC committee TC 216 started a Vilamoura process in order to write a harmonized standard for carbon monoxide (CO) gas detectors in underground car parks. Work finalized in 2011 with the publication of European EN 50545-1 standard (CENELEC, 2011). This standard includes the functional measurement requirements and type testing procedures for gases such as NO and NO_2, in addition to CO. With this harmonized standard, the requirements and know-how of experts from eight European countries were combined for safety assurance of car park users.

It was appreciated during the course of writing Part 1 that a separate standard would be required for tunnel-specific requirements. In addition to gas concentration measurements, it is also customary to measure visibility in road tunnels. Therefore, work on a second part of the standard with the subtitle "Part 2: General performance requirements and test methods for gaseous and airborne pollution measurements in tunnels" has commenced, and is now in its second year of progress. Part 2 will address requirements pertaining to the functionality and performance of toxic gas detection and visibility measuring devices within tunnels. The CENELEC working group CLC/TC/TC216/WG5 comprises a team of ten experts from six European countries.

2. CURRENT STATUS OF AIR QUALITY IN ROAD TUNNELS

In line with technological developments in engines (e.g. EURO standards), tunnel air quality has changed in road tunnels over the past few decades (Vidal et al., 2019), as shown with the three examples provided in Table 1, Figure 1 and Figure 2:

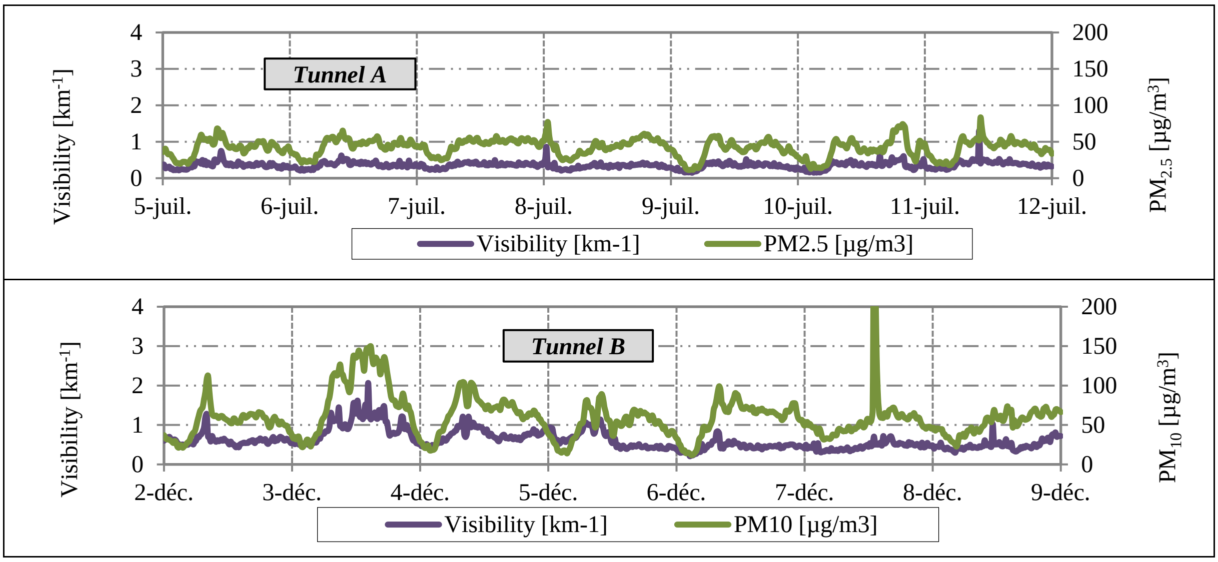
- Carbon monoxide (CO) concentrations have fallen sharply and the most commonly encountered values are of the order of several ppm or at the most 10-20 ppm.
- Visibility levels have also improved and levels are generally lower than 2 km^{-1};

- Nitrogen monoxide (NO) concentrations are generally less than 5 ppm or can rise to 10 ppm in certain tunnels depending on the proportion of heavy goods vehicles in the traffic mix. Since the concentrations found are well below the maximum recommended concentrations for short-term exposure, NO is not a relevant pollutant to be taken into account in road tunnels;
- The most problematic potential pollutant in road tunnels is nitrogen dioxide (NO_2). Concentrations of NO_2 observed are a few hundred ppb (200 to 400 ppb generally) when traffic flows smoothly in heavy traffic urban tunnels (Vidal et al, 2014). In situations with traffic congestion, these concentrations can increase up to values of 1 to 2 ppm (or sometimes more) in some tunnels if ventilation is not in place.

Situations that can become problematic in terms of tunnel air quality are mostly found in very long tunnels, in two-way tunnels and in tunnels where traffic congestion occurs, and worsened with heavy traffic.

Table 1: Tunnels characteristics and instruments implemented for the three examples

Tunnel	*A*	*B*	*C*
Type	urban tunnel / one way	urban tunnel / one way	alpine tunnel / two-way
Traffic	35 000 vehicles/day 11% HGV	65 000 vehicles/day 13% HGV	5 000 vehicles/day 50% HGV
Tunnel length *[distance from the entrance portal]*	4 km [1.2 km]	0.6 km [0.4 km]	>10 km [0.6 km]
NO/NO_2 monitor	HORIBA APNA 370 or ThermoFisher 42 i CLD (Chemiluminescence)		
CO monitor	Alphasense electrochemical cell		
Opacity monitor	SIGRIST Visguard (based on scattered light intensity measurement)		
PM_{10} and $PM_{2.5}$ monitor	ThermoFisher TEOM 1400ab (Tapered Element Oscillating MicroBalance)		



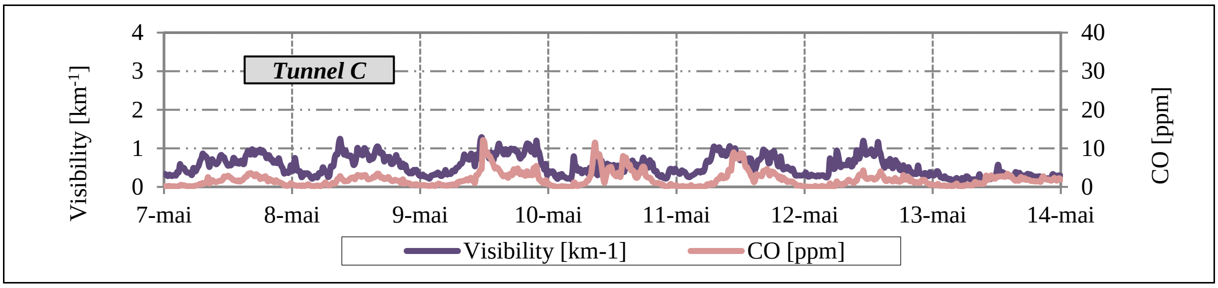


Figure 1: Three examples of CO, PM_{10} and $PM_{2.5}$ concentrations and visibility levels

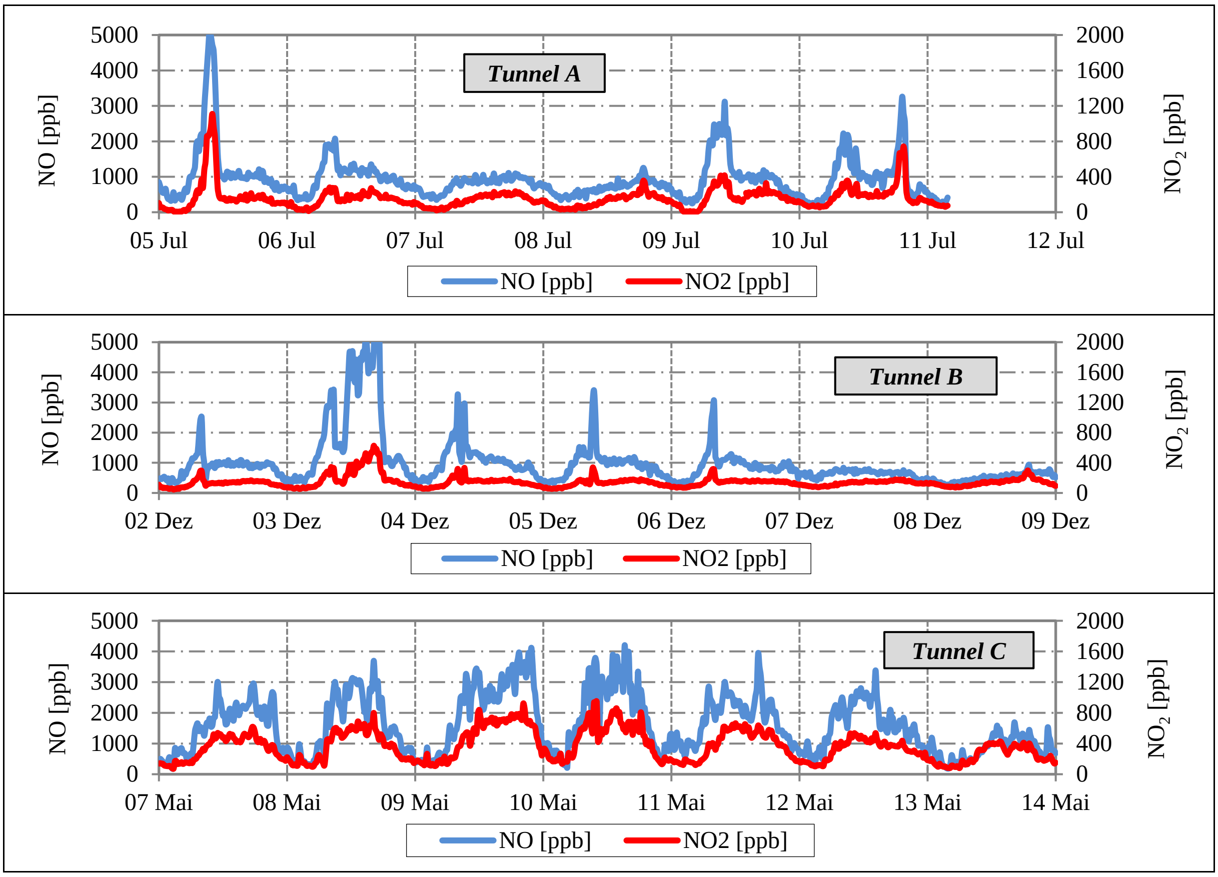


Figure 2: Three examples of NO and NO_2 concentrations measurements

The strategy adopted to improve air quality in road tunnels is to dilute pollutants by providing a large intake of fresh air injected by ventilation systems that are typically capable of delivering 100 to 300 m^3/sec (Vidal et al, 2016). Such solutions come at a cost in terms of high energy consumption with the ensuing budgetary implications and negative environmental impacts caused by the need to generate such energy. To ensure ventilation is scaled in such a way as to control energy consumption, operators should use the appropriate tools, including accurate pollution sensors to reliably and sustainably monitor air quality in their tunnels in real time.

3. LABORATORY TESTING

An essential part of EN50545-2 is the definition of laboratory tests and the conditions under which these tests should be carried out. These well-defined laboratory tests make the performance of measuring instruments from different manufacturers comparable. The quality criteria for the tests are based on the requirements emanating from road tunnel usage. Thus, these laboratory tests ensure that the measurement performance of any measurement device which has passed these tests is suitable for use in road tunnels and that it corresponds to the state of the art. All tests should be carried out by certified test laboratories.

This makes it possible to make tendering specifications very simple, clear, suitable for use in tunnels, and in accordance with the state of the art – just by referencing EN 50545-2. These tests thus eliminate the tedious compilation of individual measurement requirements in tender specifications and help to avoid ambiguous or contradictory specifications. A fair and open competition between suppliers can thereby be assured.

The lab tests of Part 1 of EN50545, are designed for testing electrochemical cells measuring the gas components CO, NO and NO_2. In Part 2, the visibility which is measured in almost all road tunnels is also covered. For this purpose, suitable and practically feasible test procedures and test equipment are defined. In part 2, the test methods for gas measurement devices are described in such a way that they are also applicable to the methods commonly used in road tunnels for measuring gas concentrations, such as electrochemical cells, open path NDIR spectroscopy, open path DOAS measurement devices and single wavelength absorption spectroscopy.

The standard distinguishes between test procedures and devices for gas and visibility measurements. For gas measurements, the lab tests are carried out mainly by applying different gas concentrations. For visibility measurements, it introduces the use of a base calibration. This base calibration must take into account the light spectrum in the tunnel (Kuhn, 2018) and the particle size distribution in road tunnels. A direct measurement of the visual range as perceived by tunnel users is not possible. Therefore, two indirect measurement methods are used: transmission based instruments measure the attenuation of emitted light over a certain distance, and scattered light instruments count the particles in the measuring volume. It is not possible to produce a homogeneous particle distribution over the measuring section for both instrument classes. To cope with this limitation, the standard proposes the use of surrogates. For transmission-based instruments, it proposes neutral density filters and for scattered light monitors it proposes scattering plates.

As far as possible, the requirements and description of the test methods are formulated in a generally valid manner so that any new measurement methods can be easily incorporated.

Other important differences compared to the test methods described in Part 1 result from the different measuring ranges that are usually used to control the ventilation of road tunnels. Especially for the gases NO and NO_2, significantly smaller measuring ranges are used in road tunnels. For measuring NO_2, the standard covers two different classes of devices: 0...2ppm and 0...5ppm, corresponding to the measuring ranges used in different geographic regions. Some recommendations on admissible concentrations and operations limits are provided by PIARC (PIARC, 2019). The testing of interfering gases is adapted in Part 2 to the pollutants occurring in road tunnels in relevant concentrations.

The scope of the laboratory tests is quite comprehensive, with 15 different descriptions of laboratory tests listed in the standard. This ranges from simple verifications of warm-up times or response times to the more complex linearity and repeatability tests, tests of cross-sensitivities and other tests which check the impact of varying ambient conditions such as temperature, humidity, etc. Finding reasonable test procedures for temperature tests of open path type devices with long path lengths turned out to be rather challenging as the climate chambers, which are available at typical testing laboratories, are simply not large enough to put such system into it with standard measurement path length. Nevertheless, with the advice of an established test laboratory, the working group is on the way to finding a solution for this.

The extensive tests within the framework of EN50545-2 thus significantly increase the confidence that buyers can have in these measuring instruments. They cover far more than any factory acceptance test (FAT) or even a site acceptance test (SAT) could ever cover. FATs and/or SATs can thus be made much easier and less expensive, or even be dispensed with altogether. Together with the field tests described below, a very comprehensive and robust proof of the suitability of such devices for road tunnels is provided by this standard.

4. FIELD TESTING

The challenge for any instrument certification process or standard is that not all operating conditions can be fully replicated in a controlled laboratory environment, and end users need the confidence that instruments will work in their tunnel. Therefore, an important aspect of this standard is that the analyser's performance must be proven in the real world as well as the controlled laboratory environment. To do this, two instruments will be mounted in close proximity to each other in a road tunnel meeting predetermined conditions, to ensure that the test location is truly representative and sufficiently demanding. The instruments will then be closely monitored along with repeated independent tests over an extended period of time allowing the true performance and maintenance intervals to be determined.

The testing within the tunnel will allow relevant data for repeatability to be obtained (ensuring both systems work together) along with span drift, zero drift, the effect of temperature and any effects due to contamination build-ups. The maintenance interval will be an important finding of these trials and should determine the maximum amount of time the instruments can operate without intervention. To determine this interval, the instruments will be repeatedly exposed to calibration checks using protocol gas or interference filters without adjustment over a period of 3 to 6 months (or more by arrangement). These checks will also highlight any effects of contamination from the environment such as reduction in sensitivity, response time or optical contamination, and the certification process will thereby define a set maintenance interval for each tested model of instrument. This information is vital for tunnel operators as different measuring technologies will require different rates of intervention once installed to maintain reliable readings, with the knowledge that any intervention costs time and money in a tunnel.

Finding such test tunnels can be a challenge for manufacturers and certification groups alike. The complexities of repeated access to instruments under test means that the help and understanding of tunnel operators is necessary to make this happen.

This part of the certification process is designed to highlight strengths and weaknesses of the instruments and their resilience to the harsh environment of the road tunnel, giving tunnel operators the confidence that the instruments they use have been proven.

5. TYPICAL AIR QUALITY MEASUREMENT TECHNOLOGIES

5.1.1. Scattered light monitors

When an electromagnetic light wave hits a particle, a certain amount of light gets scattered. Scattered light monitors count the particles in the measuring volume, by integrating the resulting light scattered energy over a certain time. Scattered light monitors have a linear response to the number of particles in the tunnel air, and thus provide a measurement of visibility.

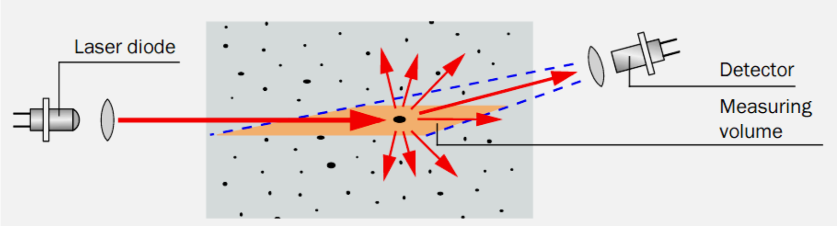


Figure 3: Scattered light monitor

5.1.2. Transmission based instruments

Transmission based instruments measure the attenuation of emitted light over a certain distance. Following the Beer-Lambert Law, the transmission value has a non-linear behavior with respect to dust concentration. Therefore, the measurement of the light attenuation can be used as an indicator of visibility in road tunnels.

5.1.3. Gas measurements – differential optical absorption spectroscopy (DOAS)

Gas molecules are excited by electromagnetic radiation. This excitation occurs at wavelengths which are typical for the gas in question.

If electromagnetic radiation of a certain wavelength encounters a suitable molecule, the radiation excites the molecule and at the same time loses energy. The molecule absorbs energy. The more molecules of a certain gas there are, the more the radiation is absorbed in this area.

With differential optical absorption spectroscopy (DOAS), light is emitted from a sender or a lamp, travels through a measuring distance, and then encounters a receiver.

The receiver splits the light into a spectrum. This enables you to detect how much energy is absorbed at which wavelength by the gases that are present.

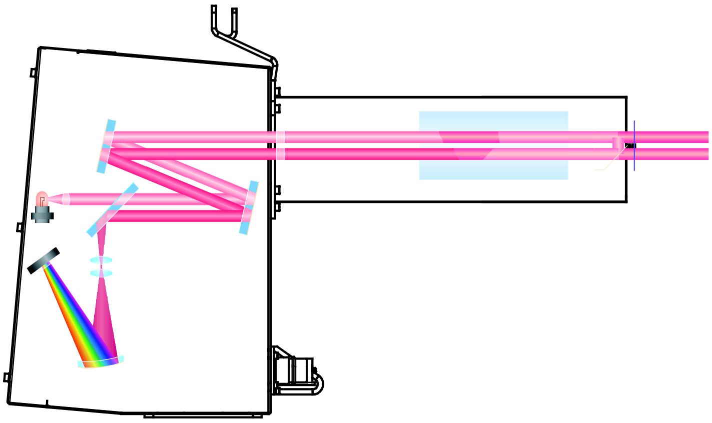


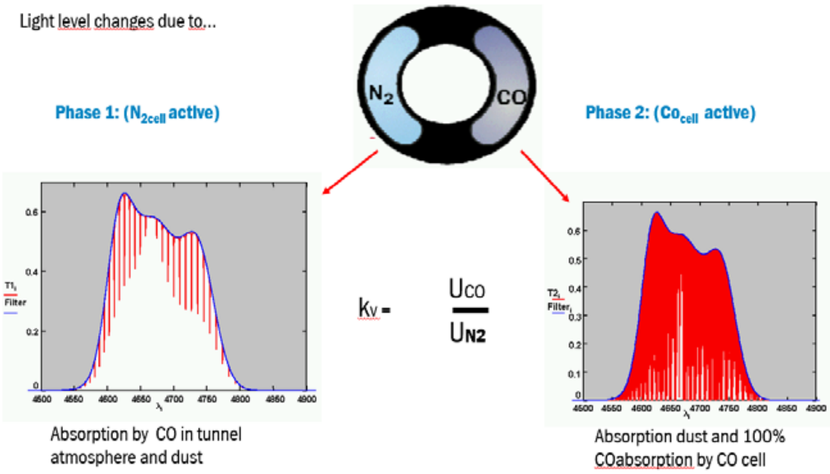
Figure 4: Differential optical absorption spectroscopy (DOAS)

5.1.4. Gas measurements – gas filter correlation

Gas filter correlation is a form of nondispersive infrared spectroscopy. The background level of radiation is measured by inserting a concentrated sample of the gas to be analysed. This filters out the wavelengths which are specific to that molecule.

Two gas filled cuvettes are mounted on a rotating disc. This passes through a beam of light alternately. The measurement cuvette is filled with nitrogen while the reference cuvette is filled with a sample of the gas to be measured.

Infra-red light passes through the gas to be measured and the difference in absorbance is measured and provides a direct output of the gas concentration.



5.1.5. Electrochemical cells

Electrochemical cells are a relatively new technique of gas measurement within road tunnel environments and have quickly become the norm for many markets around the world. There is a growing body of literature documenting the performance and application of electrochemical cells outside road tunnels as they are often used as compact, low-cost, and portable gas sensors. It has been demonstrated that electrochemical sensors have high potential for use in ambient air quality monitoring applications by virtue of their accuracy. However, the impact of ambient conditions and cross interference of gases should be carefully taken into account (Wei et al, 2018). The cells themselves produce an electrical charge directly proportional to the amount a toxic gas they are exposed to which is in turn is measured by the instrument to give a relative concentration level. The cell's ability to produce this electrical output is dependent on many factors and only last for a limited time (similar to a battery) and the manufacturers have to ensure their instruments overcome several technical challenges to ensure the cells give a reliable output. Electrochemical cell-based instruments work on diffusion of the gas into the instrument, and typically offer fast response times. However, these instruments require more upkeep than an optical device and are therefore typically designed such that maintenance work such as cell calibration and replacement is as quick and easy as possible.

6. RELATIONSHIP TO A NEW ISO STANDARD

A related standard is being developed independently by the International Organization for Standardization (ISO) Air Quality technical committee (ISO/TC 146). This standard is ISO-23431 "Measurement of Road Tunnel Air Quality", it is currently at the DIS stage (draft international standard) and is due to be issued in early 2021.

The scope of the ISO standard is as follows *"This Standard describes methods for determining air speed and flow direction, carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO_2) concentrations and visibility in road tunnels using direct reading instruments. This Standard specifically excludes requirements relating to instrument conformance testing"*.

The main aim of the ISO standard is to provide calibration and check procedures that can be used by road tunnel operators after the air quality monitoring equipment has been installed and commissioned in the road tunnel. The procedures and methods described in the ISO standard can be used as a quality control to ensure the ongoing correct operation of the monitoring instruments.

The in-tunnel test procedures proposed in ISO-23431 are very thorough. The standard requires a multi-point linearity test to be performed after commissioning, and this test must be repeated every 12 months. An interim 6-monthly single point span test is also required. This process has been developed based on experience with existing, well established, road tunnel air quality monitors, for which there is no independent conformance testing. As a result, the proposed in-tunnel procedures and test methods are very rigorous, but valid only for conventional monitoring technologies.

In contrast EN-50545-2 is an instrument conformance standard. It defines performance criteria to be met by the monitoring instruments and provides the test methods to be used to demonstrate this performance. This conformance testing is independent of the technology used by the monitor and therefore does not restrict the types of monitoring instruments that could be used.

One of the primary aims in developing the conformance standard EN-50545-2 was to help tunnel operators control the maintenance costs of in-tunnel air quality monitors. The proposed instrument testing will demonstrate the accuracy and linearity of the monitoring instruments, thereby removing the need to perform multi-point linearity testing in the tunnel. The standard also specifies in-tunnel field testing of the monitors, which will provide quantifiable information on the minimum maintenance interval. This will allow the correct maintenance schedules to be determined for the equipment being used, and not having to adopt the fixed timescales defined in the ISO standard.

7. SUMMARY AND CONCLUSIONS

The nature of airborne pollution within road tunnels has changed over the past few years, due to improvements in engine technology. This has reduced the importance of CO and visibility as the most onerous pollution criteria, and emphasised the importance of NO_2 and particulate matter as the key variables for tunnel air quality. The new CENELEC standard EN-50545-2 aims to address the need for robust, accurate air quality sensors that can be installed in a harsh tunnel environment with minimum maintenance, thus meeting the requirements of tunnel owners and operators.

8. REFERENCES

CENELEC (2011) *EN 50545-1 Electrical apparatus for the detection and measurement of toxic and combustible gases in car parks and tunnels, Part 1: General performance requirements and test methods for the detection and measurement of carbon monoxide and nitrogen oxides,* European Standard.

Kuhn, Ch. (2018) *Visibility measurement in tunnels – Adjustment of visual range measurement values*, SICK AG.

PIARC. (2019) *Road tunnels: Vehicle emissions and air demand for ventilation,* Technical committee D5 Road Tunnels – World Road Association

Vidal, B., Yaghzar, M., Burkhart, JF., Grand, J.P., Liu, Y., Martinet, S., Petit, JF., Coulbaux, G., & Hallemans, E. (2019) *Measurements of particulate matter (PM) concentrations in road tunnels taken between 2009 and 2018,* TAP conference.

Vidal, B., Burkhart, JF., Preterre, D., Gouriou, F., & Petit, JF. (2016) *Real world performance of ventilation systems for reducing nitrogen oxides or particulate matter levels in road tunnels,* TAP conference.

Vidal, B., Bernagaud, C., Burkhart, JF., Grand, J.P., Preterre, D., Gouriou, F., Petit, JF., Le Priol, T., Guilloteau, A., Barbe, P., & Bouquet, M. (2014) *Nitrogen oxides and particles matter levels in the tunnels of the Ile-de- France motorways network,* TAP conference.

Wei, P., Ning, Z., Ye, S., Sun, L., Yang, F., Wong, KC., Westerdahl, D., & Louie, PKK. (2018) *Impact Analysis of Temperature and Humidity Conditions on Electrochemical Sensor Response in Ambient Air Quality Monitoring,* https://www.ncbi.nlm.nih.gov/pubmed/29360749