LASER COMPONENTS®

Spectroscopy Helps Tuning Down Air Pollution

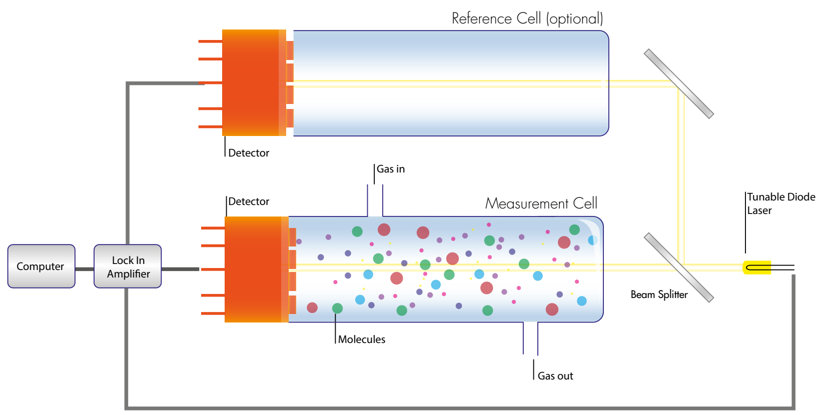
Roadside Monitoring

It took less than a century for cars to become an indispensable part of our modern lifestyle. They keep us mobile and take us to faraway places. For many of us, even routine affairs such as the daily commute would be unthinkable without cars. But the flip side of the coin has become as obvious as the advantages: vehicular air pollution affects air quality in both metropolitan and small-town areas all around the world. Stratospheric ozone depletion and toxic air pollution are among the most pressing issues of our time.

To combat air pollution in the U.S., Congress enacted the Clean Air Act (CAA) in 1963 pertaining to air quality and ozone protection. The '65 amendment added the Motor Vehicle Pollution Control Act to set the first automotive emissions standards with restrictions on fuel and engine production and plans to measure and report respectively. Its counterpart in Canada, the On-road Vehicle and Engine Emission Regulations under the Canadian Environmental Protection Act (CEPA), was introduced in 1999 to be more stringent than previously set regulations and aligned with those of the U.S. Throughout Europe, politicians have also implemented a diverse range of measures to limit exhaustion of CO_2, greenhouse gases, and particulate matter. In some cities, only cars with even numbers may drive on even-numbered days, while elsewhere people must pay considerable fees to get admittance to city centers.

Real-life Implementation

In 2015 experts from the European Union, Japan, and India agreed on the Worldwide harmonized Light vehicles Test Procedure (WLTP) following the guidelines of the UNECE World Forum for Harmonization of Vehicle Regulations. Any new model produced after September 2017 must comply with these regulations. In addition to the usual lab tests, cars must also undergo a so-called Real Driving Emissions (RDE) test following clearly defined statistical guidelines. Some pollutants, such as nitrogen ox-ides (NOx), cannot be determined under lab conditions but need to be tested in a driven car. Therefore, the RDE test will certainly deliver more accurate and extensive results. Some scientists, however, state that the bulky equipment commonly used for RDE testing leads to unreliable results because it changes the aerodynamics and weight of the car.



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Instead, they propose TDLAS systems that would easily fit into the trunk of the car. Their detection units could be attached to the exhaust pipe without any convoluted constructions.

Controls for used cars have also been streamlined. After a maximum period of four years before the first check-up, every car must periodically undergo a vehicle inspection, which includes an emissions test. In most European countries, these checks are conducted every two years. Following these regulations, there is a certain need for every car on the road to meet governmental standards. Outside the EU, the picture is a little bit more confusing.

In the U.S. and Canada regular vehicle and emissions tests are part of state or provincial legislation. The aforementioned CAA merely requires the implementation of vehicle emissions inspection programs in metropolitan areas where air quality does not meet federal standards. Therefore, there are virtually fifty different regulations within the U.S.; sparsely populated states like Wyoming and Alaska do not feel the need for any inspection whatsoever.

Fixed Monitoring Stations

In many cities around the world, pollution measurements are also conducted by fixed metering stations. The concentrations of pollutants such as SO_2, H_2S, CO, NO, NO_2 or ozone are monitored on a 24-hour basis, often using a different method for each substance. Sulfur compounds may be measured using UV fluorescence, NOx values are determined by chemiluminescence, and CO is determined by IR absorption. This is a useful strategy to obtain an overview of the overall pollution. These stations do not differentiate between vehicular, industrial, and domestic pollution but provide an overview of the overall air quality at a specific point and time. Many of them are placed in heavy traffic areas; it can, therefore, be concluded that variations of certain pollutants are mainly caused by vehicle emissions. These stations are the main source for pollution values as commonly mentioned by the media. According to the U.S. EPA (Environmental Protection Agency), the emissions of air toxics declined by 68% from 1990 to 20141.

Roadside Measuring

It appears that North America and Europe have found a way to keep track of their pollution and started taking measurements. But there is great potential for developing countries to reduce their production of CO_2 emissions. In 2014, the World Health Organization (WHO) declared New Delhi the dirtiest city in the world regarding particulate matter. To cope with these problems, Indian scientists have come up with a reliable, cost-effective, and easy-to-use method for roadside measurement of vehicular emissions:

At the LASER COMPONENTS IR WORKshop in 2016, Dr. T.K. Subramaniam of the Department of Science & Humanities (Physics) at Sri Sairam Engineering College in Chennai, India proposed a laser-based method that would allow the in-situ roadside measurement of all pollutants in a single scan. He applied Tunable Diode Laser Absorption Spectroscopy (TDLAS), which builds on well-known spectroscopic principles and uses sensitive detection techniques, coupled with tunable diode lasers and optical fibers developed by the telecommunications industry.

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TDLAS is a sensitive detection method that uses a tunable diode laser to determine not only the existence, but also the concentration of a substance in a medium. According to the Beer-Lambert extinction law, the amount of attenuation in a light pulse depends on the concentration of the absorbing molecules and the path length over which absorption occurs. As light traverses a medium containing an absorbing analyte, decreases in intensity occur as the analyte becomes excited. This means that for a given path length attenuation increases with the concentration of absorbers. Semiconductor lasers can be tuned in wavelength to match distinctive absorption lines. By transmitting a beam of light through a gas mixture containing a (usually trace) quantity of the target gas, tuning the beam's wavelength to one of the target gas's absorption lines, and accurately measuring the absorption of that beam, one can deduce the concentration of target gas molecules integrated over the beam's path length. This measurement is usually expressed in units of ppm-m.

Dr. Subramaniam proposes the use of TDLAS measuring systems for the roadside monitoring of exhaust gas emissions. To get results that reflect the average pollution rate of a car, measurements must be made at a time when the engine has been running for several minutes. The catalytic converters usually need three to five minutes to reach their operating temperature, during which time carbon monoxide and unburned hydrocarbons are released into the air. The emission of nitrogen oxides also in-creases with the motor load. Measurements, therefore, will have to be conducted on road sections on which cars are indeed driven. According to Dr. Subramaniam, highway intersection ramps and toll plazas would be the best spots for roadside exhaust controls. "At intersections, the motor has been running for a considerable amount of time; driving uphill puts additional strain on the combustion system. The ramps could, therefore, be used to check the emissions and environmental effects of each vehicle. At toll plazas, a number of instruments could be used simultaneously when the vehicles are at „idling condition" after running through long distances. In these places, it may be possible to add supplementary sensors to capture vehicle payload and other values that affect emissions", says Dr. Subramaniam. "If the vehicle being tested is found to have emissions which violate the rules of the day as prescribed by a government of the day, a high-speed camera is activated within a microsecond or a picosecond to take a photograph of the license plate of the vehicle and the driver of the vehicle, as well as to note other details like the time and place of booking, etc. The driver will then be notified that his car needs maintenance. In grave cases, tough consequences could be implemented. If the car complies with regulations, the driver receives a badge showing proof of successful control." He is convinced that "TDLAS is a fool-proof method to detect and control vehicular emission. Remote sensing instruments can measure the emissions of thousands of vehicles per day."

Some U.S. states follow a similar strategy by conducting mobile roadside emission tests – not unlike speed traps or alcohol tests. Experts state that compared to station-based tests, roadside controls can check thousands of in-use vehicles under real-life conditions. The data collected "on the road" could be used to improve government or manufacturer programs. For example, they could be used to find out builds or models with particularly high pollution rates and thus help discover design flaws.

Dr. T.K. Subramaniam

Dr. T.K. Subramaniam has been working as a professor of physics at Sri Sairam Engineering College, Chennai, India for more than twelve years. As a renowned specialist in the field of laser spectroscopy, he has twenty-nine years of experience in re-search and industry. In 2004, he earned his PhD from the famous Banaras Hindu University (BHU) in Varanasi, India, where he also helped to establish a laser spectroscopy laboratory. His work includes twenty-three research publications in international journals of repute and a textbook on Engineering Physics recently published by the Oxford University Press (OUP). He also serves as a peer reviewer for the Optical Society of America (OSA) group of journals, i.e., the Journal of the Optical Society of America and Applied Optics, USA.

1 https://gispub.epa.gov/air/trendsreport/2018/#air_pollution

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