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Optical sensing of hazardous exhaust emissions using a UV based extrinsic sensor

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Abstract

A fibre-optic sensor for the monitoring of hazardous exhaust gases is described. The sensor based on ultraviolet (UV) differential optical absorption spectroscopy (DOAS) was developed for the simultaneous monitoring of several exhaust gases from passenger cars. Experimental results describing the operation of this sensor with calibrated cylinder gases as well as in a full-size engine are presented. The sensor has been developed to operate within an exhaust environment and have low susceptibility to interferences from other gases present. The lower limit of detection for the sensor was found to be 5 ppm for nitric oxide (NO), 1 ppm for both nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) and response time was found to be 3.4 s.

Keywords: UV gas sensor; Spectroscopy; Pollution monitoring; DOAS

1. Introduction

Since the industrial revolution in the mid 1800s, worldwide energy consumption has been growing steadily. In developed countries historic air pollution problems were typically high levels of smoke and SO_2 arising from the combustion of fossil fuels such as coal for domestic and industrial purposes. However, with the introduction of modern passenger cars and vastly increased demand for power, the twentieth century saw rapid increases in the use of fossil fuels. Between 1980 and 2004, the worldwide annual growth rate has been 2%.

While some alternatives to oil exist in the residential and industrial areas there are currently few suitable alternatives in the automotive industry. The widespread use of the all-electric engine is still years away [1], while the bio fuels industry is still too small to make an impact against the global oil industry [2]. Over the next 30 years oil demand is expected to grow by 60% as the transportation systems of developing economies become increasingly motorised [3]. This sustained increase in demand means oil consumption is expected to increase from an estimated 78.6 million barrels a day in 2003 to 119 million barrels a day by 2025 [4]. Despite several reports predicting the imminent exhaustion of oil reserves, the mainstream view is that there are still significant reserves of oil to last several decades [3,5]. Increase from an estimated 78.6 million barrels a day in 2003 to 119 million barrels a day by 2025 [4]. Despite several reports predicting the imminent exhaustion of oil reserves, the mainstream view is that there are still significant reserves of oil to last several decades [3,5].

A growing source of concern associated with global oil consumption has been the effect the combustion of these nitrogen-bearing fuels has on our atmosphere. During combustion the nitrogen (N_2) bound within the fuel is released as a free radical and ultimately forms free N_2 or NO. In fact motor vehicles generate a wide range of pollutant gases including hydrocarbons, oxides of nitrogen, oxides of sulphur, and carbon monoxide. These emissions can cause or compound many local and global environmental issues such as acid rain, the greenhouse effect, the destruction of the ozone layer and air pollution known as "smog". In addition to these, increased air pollution can have a serious impact on human health. Air pollution has

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been associated with many major health conditions including heart failure, arrhythmia and other cardiovascular causes of death. The major threat to clean air is currently posed by emissions produced by the transport industry. In cities worldwide, the automobile is known to be a major polluter. At the end of 1995 there was an estimated 490 million vehicles in use. Today, that figure is thought to be almost 800 million, with increasing levels of air pollutants recorded throughout many parts of the world. In some western countries it is estimated that vehicle emissions kill twice as many people as road traffic accidents [6].

2. Legislation

The European Automobile Manufacturers Association (ACEA) in conjunction with the EU has taken important steps over the past decade to reduce harmful emissions with the installation of several modifications into their motor vehicles. These include fuel injection systems, catalytic converters, charcoal canisters, engine preheating, CFC-free air conditioning systems, and monitoring and warning systems. In addition to this anti-pollution and fuel consumption regulations are being introduced by environmental protection agencies throughout the world. In 1991, the European Union introduced the *EURO* directives [7–10] in which all new vehicles must comply with a set of emission regulations. The regulated emissions include particulate matter (PM), nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO). The *EURO* directive for passenger cars (category M_1) is summarised in Fig. 1.

As part of the *EURO III* directive vehicles were required to be equipped with an onboard diagnostic system for emission control. Drivers should be notified in case of a malfunction or deterioration of the emission system that would cause emissions to exceed mandatory thresholds, shown in Fig. 2.

To control greenhouse gas emissions from the transportation sector, the European Commission has signed voluntary agreements with the European Automobile Manufacturers Association (ACEA) to reduce the emissions of CO_2 into our atmosphere.

- Individual ACEA members to introduce models of 120 g/km or less by 2000.
- Intermediate target range of 165–170 g/km by 2003.
- CO_2 emission target of 140 g/km to be reached by 2008.
- Possibility to extend the agreement to 120 g/km by 2012.

Similar agreements have also been signed with the Japanese Automobile Manufactures Association (JAMA) and Korean Automobile Manufactures Association (KAMA). The total vehicles sold collectively by these

EU emission Standards for Passenger Cars (g/km)

Tier	Date	CO	HC	HC+NOx	NOx	PM
Diesel						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08
Euro 2, DI	1996.01	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
Euro 5‡	mid-2008	0.50	-	0.25	0.20	0.005
Petrol (Gasoline)						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-
Euro 5‡	mid-2008	1.0	0.075	-	0.06	0.005

* Before Euro 5, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
‡ Proposed

Fig. 1. European emission standards for passenger cars [11].

European OBD Threshold Limits (g/km)

Category	Class	Tier*	Date	CO	HC	NOx	PM
Diesel							
M_1		EU 3	2003	3.20	0.40	1.20	0.18
		EU 4	2005	3.20	0.40	1.20	0.18
Petrol (Gasoline)							
M_1		EU 3	2000	3.20	0.40	0.60	-
		EU 4	2005	1.90	0.30	0.53	-

* Euro 4 threshold limits are proposed values, still under discussion
Note: Passenger cars category M_1 > 2,500 kg or with more than 6 seats meet OBD requirements for Category N_1.

Fig. 2. European on-board diagnostic threshold limits for passenger cars [11].