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The environmental impact of vehicle emission standards

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Abstract

Vehicle emission standards are becoming an increasingly important instrument for the improvement of air quality in urban areas. With the introduction of Urban Clear Zones and Low Emission Zones it will be necessary not only to set targets for air quality but also emission standards for vehicles permitted to enter such zones. So far such standards are being introduced through continental wide programmes. Their application to individual zones as a local air quality or environmental management measure is an option for the future.

This paper reviews the EURO I and II standards in Europe and the California CARB measures and the future standards EURO III and IV and the US standards LEV, ULEV, NZEV and ZEV. The measured and predicted trends in urban NO_x emissions are compared over the period 1993-96.

The concept of the Urban Clear Zone and the Low Emission Zone is discussed together with the likely impact on vehicle emission standards and on the design of vehicles required for access, and in particular, propulsion technologies.

1 Introduction: Vehicle emissions legislation

Exhaust emissions from vehicles have been subject to regulation since the 1970s. During this time standards in the US have been more stringent than those in Europe but standards throughout the EU and the US are becoming comparable. The emissions standards apply to passenger cars, vans and heavy duty vehicles (trucks and buses). The European Directives are concerned with exhaust emissions of carbon monoxide, total hydrocarbons, oxides of nitrogen and particulate matter (diesel vehicles only). The current legislative position is known as Stage 2 or Euro 2 emission limits and these provide for production vehicles being 70% to 80% cleaner than those built in 1970 (Hitchcock[1]).

2 The Auto-Oil programme

2.1 Requirements

The latest requirements for vehicle exhaust emissions and fuel quality standards, due for 2000 and 2005, have been developed within the remit of the European Commission's Auto-Oil 2000 programme. The automotive industry, the fuel industry and the Commission collaborated in the Auto Oil programme to establish the most cost effective vehicle technology and fuel combinations to meet future air quality objectives. The European Council of Ministers and Parliament adopted the Commission's 1996 Auto Oil Package measures in July 1998. These measures included the Stage 3 and 4 emissions limits for passenger cars shown in Table 2. The air quality objectives of the programme were based on the WHO's health and environmental guidelines. There were three parts of the Package with the potential to reduce total overall vehicle emissions by up to 70% in 2010 compared with the 1990 level (Hitchcock[1]). This reduction is forecast even when taking into account the expected increase in traffic volumes.

The Auto Oil Package contains two Directives covering exhaust emissions from passenger cars and vans, and a third Directive on petrol and diesel-fuel quality. There is also a requirement to ensure that vehicles will be fitted with on-board diagnostics (OBD) which will warn the driver, and latterly the servicing mechanic, that the vehicle is polluting. In addition there will be provision to test durability of vehicles by surveying aging vehicles. If the sample shows that emission controls on a vehicle lose effectiveness the onus will be on the manufacturer to recall and rectify all of those vehicles in the fleet (Hitchcock[1]). There is also a proposal for a Directive on emissions from heavy vehicles such as lorries and buses.

2.2 Impact so far

Indications from urban measurements in the UK indicate that the concentrations of NO_x, CO and PM_{10} are leveling off having followed a trend governed by traffic growth. Table 1 shows trends in these concentrations, together with estimated trends in vehicle NO_x emissions. The estimations appear optimistic, however, indicating that the measures introduced so far have not had the expected effect on urban NO_x concentrations.

Table 1. Measured and estimated trends in pollutants (UK) (Bush[(2)], 1998)

	units	1993	1994	1995	1996
Bristol					
NO_x	PPb	71	62	63	59
CO	PPm	0.8	0.7	0.6	0.5
PM_{10}	μgm^{-3}	27	24	24	25
NO_2, UK average. PPb					
Kerbside		23	24	25	24
Intermediate		17	17	18	17
Urban background		15	14	14	14
Estimated (predicted) UK NO_x emissions, ktonnes					
Total, UK		2408	2297	2145	2060
Road transport, Petrol		670	625	582	543
Road transport ,DERV		494	484	448	423

Source for Bristol data ref. 3

3 Passenger car standards

3.1 EU

The first regulations applied to EU passenger cars seeking type approval from 1970. Since then progressively tighter regulations have been introduced. In 1991 the regulations were thoroughly reviewed and the regulations (91/441/EEC) applied to type approval of passenger cars from 1993, and effectively required the use of a three-way catalyst for petrol cars (NSCA[4]). These regulations are commonly known as Stage 1 or Euro 1 emission limits. Vehicle emissions in 1993 were approximately 80% less than those of vehicle operating in 1970 (Hitchcock[1]).

Table 2 illustrates the effect of the further tightening of the regulations from the introduction of stage 1 limits in 1993 through to the stage 4 limits now agreed for introduction in 2005. In effect the limits require a 50% reduction in passenger car exhaust emissions.

Table 2. EU Emissions Legislation for Passenger Cars

	Date	**Emissions in g/km**				
		CO	**HC**	**NOx**	**HC+NO$_X$**	**PM**
Stage 1	1993	2.72			0.97	0.14
Stage 2	1996	2.2 (1.0)			0.5 (0.7)	(0.08)
Stage 3	2000	2.2 (0.64)	0.2	0.15 (0.5)	(0.56)	(0.05)
Stage 4	2005	1.0 (0.5)	0.1	0.08 (0.25)	(0.3)	(0.025)

Notes: Values in ( ) are for Diesel vehicles
Source: Hitchcock[1]

3.2 California

The USA, and in particular California, has been the responsible for the introduction of strict emission reduction requirements for vehicles which have, over time, been adopted by many other nations. Table 3 shows the current emissions limits for passenger cars in California. These limit values are now comparable to those in the EU. For example the Californian Low Emission Vehicle (LEV) standard is similar to the EU stage 3 limits and the Ultra Low Emission Vehicle (ULEV) standard is broadly comparable to stage 4 EU limits (Hitchcock[1]).

Table 3 Californian Emission Limits for Light Duty Vehicles (Hitchcock[1]).

	Date	Emissions in g/km				
		CO	**HC**	**NOx**	**HC+NOX**	**PM**
Current	1996	2.11	0.078	0.25	0.328	0.05
LEV		2.11	0.05	0.12	0.17	0.05
ULEV		1.1	0.02	0.12	0.14	0.02
ZEV		0.0	0.0	0.0	0.0	0.0

The major difference between the legislation in the EU and California is the way in which it is applied. In the EU all new vehicles produced past a certain date must comply with the regulations, whereas in California increasing (and specified) proportions of the vehicles sold by each manufacturer must meet each of the more stringent standards by certain dates (Hitchcock[1]). Implementation of the emission requirements is therefore phased over a period of time.

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4 Van emission standards

In the EU the first vehicle emissions legislation specifically relating to vans was introduced in 1994 (93/59/EEC) (NSCA[4]). The limit values are related to those in force for passenger cars but are defined separately for three weight classes. The lightest class covers car derived vans, and the emission limits are therefore identical to those applying to passenger cars. There are two further weight classes up to a maximum of 3.5 tonnes. Beyond 3.5 tonnes the vehicle is regulated by the heavy goods vehicle emissions legislation (Hitchcock[1]). Stage 3 standards for petrol and diesel engines come into force in 2000 with a 4th Stage due to be introduced in 2005. Each new stage introduces progressively stricter limits on emissions of regulated pollutants.

5 Heavy goods vehicles

Emission limits for vehicles over 3.5 tonnes were first introduced into the EU in 1982 (ECE regulation No.49) (NSCA[(4)], 1998) and by the time EC Directive 88/77 was adopted HGV emissions were some 30% lower than those in ECE 49 (Hitchcock[1]). Since 1990 the legislation has followed a similar pattern to that for passenger cars, with Stage 1 and Stage 2 limits being set by virtue of a new directive, 93/59/EEC. The major difference between heavy duty emission limits and those for passenger cars is that they are related to unit power output rather than unit distance, i.e. the limits are express in g/kWh and not in g/km. The reason for this difference is that with the larger vehicles the engine and *not* the whole vehicle is tested. The current and proposed limits, including the Enhanced Environmentally friendly Vehicle (EEV) are shown in table 4. As with passenger cars the limits for 2000 were derived from the Auto-Oil programme.

Table 4: EU emissions limits for heavy engines (DieselNet[(5)], 1999)

	Date	**Emission Limits – g/kWh**			
		CO	**HC**	**NOx**	**PM**
Pre-stage 1	1990	9.0	1.6	11.5	
Stage 1	1993	4.5	1.1	8.0	0.36
Stage 2	1996	4.0	1.1	7.0	0.15
Stage 3	2000	2.1	0.66	5.0	0.1
EEV	2000	1.5	0.25	2.0	0.02
Stage 4	2005	1.5	0.46	3.5	0.02
Stage 5	2008	1.5	0.46	2	0.02

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6 Technical measures to reduce vehicle emissions

In Europe, the process of reducing traffic emission by the setting of standards such as EURO I - V is, to some extent, a compromise between what is politically desirable and what is technically achievable. In the case of heavy goods vehicles, for instance, the standards are expected to be achievable by modifications to diesel engines such as particulate traps, within the timeframe specified. Other measures will now be summarised.

6.1 Improved exhaust treatment processes

These are often referred to as 'end of pipe' technologies. The aim is to trap particles and, as far as possible, convert CO and HCs into less harmful compounds by oxidation.

6.2 Cleaner engines

Development of internal combustion engines is continuing, aimed at improving the combustion process and, thereby, reducing harmful emissions. These developments mainly involve accurate control of the fuel air mixture and ignition timing to achieve optimal combustion. However, in reciprocating engines, there is a limit to such improvement.

6.3 Clean fuels

Air quality could be improved immediately by the introduction of cleaner fuels such as **Compressed natural gas (CNG)** This is being tested on fleet vehicles and, in some cases, has been introduced as a matter of policy. Internal combustion (IC) engines will run on CNG, which is largely methane, with minimal air pollution. However, there is the risk of unburnt methane, a potent greenhouse gas, aggravating global warming. There is also the penalty of the increased cost of refueling infrastructure.

Liquid petroleum gas (LPG), usually in the form of propane, is also a satisfactory fuel for IC engines, with less pollutant combustion products than conventional fuel. It is already marketed as a fuel for domestic use and is becoming more widely available for vehicle fleets. However, it also carries a cost penalty relative to conventional fuels.

Methanol is a liquid fuel for which spark ignition engines can be adapted. Though primary pollutants are reduced, there is concern at the possible emission of aldehydes which could increase the toxicological impact (Whitelegg[6]).

Ethanol is already used widely in countries where oil is scarce and energy crops, from which ethanol can be distilled, are abundant. However ethanol production is more costly than petroleum fuel and there is also concern about aldehyde emissions.

Hydrogen is of increasing interest as a fuel because its combustion is virtually emission free, the combustion product being water vapour, it is efficiently converted to electrical power by fuel cells and it can be produced by electrolysis of water using off peak electricity from non-fossil energy sources. However, at present there is a severe penalty in the cost of production and transport and the provision of compression or cryogenic facilities needed for refueling and on-board storage.

6.4 Higher efficiency

The efficiency of internal combustion engines continues to improve, with further scope in waste heat recovery. This leads to lower fuel consumption and emissions. Aerodynamic design of the vehicle body aimed at ever reducing drag coefficients can also reduce fuel consumption and emissions, particularly at motorway speeds. A further source of energy consumption is in wheel losses. There is scope for improvement in tyre and suspension design to minimise these losses. Table 5 shows the distribution of energy consumption by an average family car (Hughes[7]). The remainder of the total energy is mainly made up of engine and transmission losses which are assumed to be proportional to transmitted energy.

Table 5: Distribution of energy dissipation in a typical car.

	Proportion of total energy	proportion of transmitted energy
Air resistance	4%	22%
Rolling resistance	6%	33%
Braking	8%	45%
Total	18%	100%

6.5 Brake energy recovery

It is estimated that in urban use, up to 45% of the energy consumed by vehicles is dissipated in the friction brakes and that brake energy recovery could result in up to 30% fuel savings in urban conditions and thus up to 5% of global CO_2 emissions (Ackerman[8]). Electric and hybrid vehicle technology both provide the opportunity for brake energy recovery because of the energy storage facility which is able to accept it. The reduction in harmful emissions is even greater in hybrid vehicles than CO_2 reduction because optimal conditions under which the engine can operate. (Ehrhart[10])

7 Electric vehicles

Electric vehicles (EVs) have been seen as the ideal solution to problems of urban air pollution but developments have been severely hampered by the slow progress in the provision of batteries with adequate energy density and cycle life. This has resulted in a disproportionate amount of space in EVs being taken up by the batteries. A further disadvantage is their limited range and the slow recharge rate and short cycle life of the batteries. The development of the **fuel cell** presents an interesting prospect for the future, enabling quick refueling and higher range. Presently, there is still a problem of the space requirement, particularly if a reformer is incorporated for use of liquid fuels.

In many cities where range is not an issue, zero emission passenger transit vehicles are electrically propelled using either batteries, flywheels or overhead supply lines. As a choice for new routes, the last has the disadvantage of the high investment and maintenance cost and the visual intrusion of the supply infrastructure. Flywheels offer a low cost form of electrification and a viable alternative to batteries (Jefferson [12])

8 Hybrid vehicles

Hybrid vehicles (HVs) are seen as filling a gap between conventional vehicles and pure electric vehicles and incorporate most of the benefits of each. They were originally conceived as dual mode vehicles able to operate conventionally outside the city and on batteries within. Whilst this may satisfy the requirements of most users and air quality managers, there is still the problem of the excessive weight and volume of the propulsion equipment to be carried in the vehicle. There is now a move towards scaling down the requirements for hybrid vehicles. The first requirement is to be able to drive the vehicle continuously at a defined maximum speed, normally the motorway speed limit. This defines the power of the prime mover (engine or fuel cell). It is usually considerably less than the power of a conventional engine, which is sized to give the required acceleration, and can be reduced further by improved vehicle aerodynamic design and wheel design.

A second requirement is for an energy storage facility which can supplement the engine power during acceleration and accept brake energy on deceleration. The capacity and power of the energy storage thus depends only on the brake energy recovery and acceleration requirement and not on the required range. For a medium sized car this is about 100 Wh capacity with a power rating (charge and discharge) of up to 50 kW. This is currently beyond the capability of any battery. Ultracapacitors (Davies[9]) may provide a viable option for energy storage in future hybrid vehicles and these are already under evaluation in

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current hybrid vehicle designs such as the Toyota Prius. A further form of energy storage gaining wider acceptance in this application is the flywheel on account of its high specific power, storage efficiency and cycle life. The flywheel is currently the subject of trials of hybrid buses in both Bremen and Eindhoven by the companies Magnet Motor and CCM respectively (Ehrhart[10], Thoolen[11]). Where gyroscopic effects are considered a problem, the flywheel unit is mounted on gimbals, and safety considerations have also been addressed.

Flywheel energy storage is also being demonstrated on a zero emission light rail vehicle in Bristol developed by the company PPM Ltd. This runs on the same basis as the Oerlikon Gyrobus of the '50s by recharging the flywheel at each stop. No on-board engine is needed so that the vehicle is effectively zero emission. (Jefferson[12]). In a current European project, a hybrid combination of a gas turbine and flywheel is being tested and demonstrated on an ex-service Karlsruhe tram (Etemad[13]) If successful, it could form the basis for future hybrid passenger transit vehicles required to meet such standards as ULEV and EURO V. The advantages of the gas turbine, which can operate optimally on diesel fuel in this application, are the inherent low emissions due to the near complete fuel combustion and the reduced vibration and maintenance costs relative to the diesel engine. The hybrid arrangement allows the engine size to be reduced by a factor of three in urban applications (Etemad[13]) and therefore the emission per kWh of traction power are reduced correspondingly. This makes EURO V a realistic target for such vehicles in the short term, even using diesel fuel.

The development of the hybrid electric vehicle opens the way for fuel cells as prime mover because of the low constant load imposed by the transmission system. We can thus look forward to fleets of low emission vehicles in the near future and hydrogen powered zero emission vehicles in the medium term. Hydrogen supply infrastructure will continue to be a major consideration, however, until compact reformers enable the use of liquid fuels.

9 Clear zones

Emission standards could be used to define categories of vehicle to be permitted to enter defined zones. A precedent for this has been established in the creation of pedestrian zones which, at the discretion of the local authority, can permit entry of, say, disabled drivers. There is no reason why such zones could not also admit zero emission vehicles or even vehicles conforming to, say, EURO V. Selective introduction of restricted access to defined zones could stimulate the demand for zero and low emission vehicles to meet the required standards. In conclusion, hybrid vehicles could potentially meet strict emission limits such as EURO V and could therefore make a significant contribution to reducing traffic emission levels and to providing required levels of access to low emission zones.

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