LUBE-TECH

NO.31

EMISSIONS FROM MOTOR VEHICLES

There are currently over 27 million cars on the UK's roads. Gasoline (petrol) is the major fuel type used for cars and light vans, with diesel making up 14% (2001 figures) and other fuel sources making up the remaining 1%. HGVs, light goods vehicles, motorcycles and passenger service vehicles make up around 5 million vehicles, making the total number of vehicles on the UK's roads well over 30 million. However, the proportion of diesel-engined passenger cars in the UK is steadily increasing, and has now overtaken petrol-engined cars in both the upper-medium and luxury sectors, with144,632 sold in this sector during the first 9 months of this year in Britain compared with 129,540 last year over the same period (Source JATO Dynamics)

The transport related problems that we are currently experiencing will be made worse by the projected increase in UK traffic. The Department for Transport's (DfT) 10 Year Plan projects an increase in vehicle traffic of 17% from 2000 to 2010 (compared to 21% without the Plan). If current levels of vehicle emission rates are not improved, the projected increase in vehicle population would result in concomitant increases in pollution. As would be expected, pollution from road traffic tends to be greatest in urban areas due to greater vehicle concentrations and sub-optimum operating efficiencies during stop-start conditions. The environmental impacts of vehicles and their exhaust emissions include acid deposition and air pollution, global climate change and noise pollution, in addition to adverse effects on human health. Also, since the 1950s, emissions from aircraft have been increasing, posing yet further problems for the environment, both local and global. Today, the growth in air transport is faster than that witnessed for land-based vehicles.

The introduction of so-called 'pollution-free vehicles', using power from stored electricity or fuel-cells, still seems to be some considerable way into the future despite the enormous amount of research and development expended over many years. In any case, most of these types of vehicles are not pollution free, but merely shift the pollution source from the vehicle to that of the electricity or hydrogen-generating site. Wind, tidal or solar powered means of electricity generation are not likely to make significant inroads into the overall energy generation pattern for many years to come. The main ways forward at the moment in reducing pollution are the continuing improvements in fuel economies efficiencies, coupled with catalyst clean-up technology. Hybrid power units, using both internal combustion engines coupled with electric propulsion, although relatively complex and expensive to manufacture, have already shown significant benefits in fuel economies. Recent improvements in fuel economies in petrol-engined cars been achieved by relatively new technologies such as Gasoline Direct Injection (GDI) but all other things being equal, the diesel engine will always have an advantage in terms of fuel economy due to the greater calorific value of diesel fuel compared to petrol.

THE NATURE OF EMISSIONS

The motor vehicle engine emits many types of pollutants including nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2), particulates, sulphur dioxide (SO_2) and, until more recently, lead. Table 1 shows the UK emissions of these pollutants in 1999. Individually, a vehicle engine is not a particularly important source of pollution. Collectively however, they represent a major source of air pollutants in the UK.

TABLE 1: EMISSIONS FROM ROAD TRAFFIC IN THE UK, 1999

If fuel combustion is 100% efficient, then the products of combustion will be CO_2 and water (H_2O) only. However, at low loads engines are inefficient and therefore the products of incomplete combustion dominate, for example CO and Volatile Organic Hydrocarbons (VOCs) in petrol engines and carbon monoxide, VOCs and particulates in diesels. As the temperature of combustion increases, the efficiency of conversion to CO_2 and water increases. However, impurities in the fuel such as nitrogen are oxidised to NO_2. At high temperatures atmospheric nitrogen (N_2) is also oxidised to NO_2, hence at higher loads and speeds, NO_2 production dominates.

It has been claimed that emission of VOCs from motor vehicles is a problem that accounts for 40% of anthropogenic (man-made) emissions in Western Europe. Most VOCs are emitted from vehicle exhausts, although they also escape at other points within the fuelling chain. Evaporative losses can occur during filling, the so-called "fuelling loss". Losses can also occur from the engine when the car is being driven and when the engine is cooling down. VOCs are also released from the fuel tank as the temperature goes up and down during the day; this is called the "breathing loss" and is due to vapour evaporating from the petrol as the fuel gets hot.

Diesel engines work at a much higher level of compression than a petrol engine, allowing more efficient combustion of fuel within the engine. Therefore, diesels are more fuel-efficient than their petrol counterparts, resulting in lower emissions of CO_2. However, diesel engines emit larger volumes of oxides of nitrogen (NO_x) than petrol engines and most importantly, far larger emissions of particulate matter and black smoke. The black smoke component of particulate matter is almost wholly due to diesel emissions and is responsible for the soiling of buildings. Fine particulate matter is also associated with visibility degradation and has been linked with a range of adverse health effects.

The composition of diesel exhaust varies considerably depending on engine type and operating conditions, fuel, lubricating oil, and whether an emissions control system is present. Diesel engine emissions have changed dramatically over the last 30 years because of improvements in engine technology, emissions controls, and fuel formulation. Emissions of oxides of nitrogen and particulate matter from the diesel engines introduced in the late 1980s and early 1990s are significantly lower than those from older engines. As a result, characterisations of modern-day diesel exhaust cannot be used to estimate past exposures, nor can they be used reliably to project future emission profiles.

In order to reduce the polluting effect of emissions from motor vehicles, exhaust 'clean-up' catalytic convertors were introduced in 1992/3. A catalyst is a substance which accelerates the rate of a chemical reaction whilst itself remaining chemically unchanged. These convertors reduce emissions of CO, H/Cs and NO_x to the atmosphere (hence the term 'three-way catalysts') by converting these three species to water, carbon dioxide and nitrogen. Conventional catalysts incorporate both a reducing catalyst and an oxidation catalyst. In both types the catalyst is coated on a fine honeycomb of ceramic material over which the exhaust gases flow, so as to maximise the surface area of catalyst exposed to the exhaust gases. In the reduction zone, nitrogen oxides are reduced to nitrogen and water, whilst in the oxidation zone, unburnt hydrocarbons and carbon monoxide are oxidised to water and carbon dioxide. Platinum and rhodium are generally used in the reduction zone, whilst platinum and palladium are used in the oxidation zone. Such catalytic convertors only operate efficiently at relatively high temperatures, so are ineffective for short vehicle journeys.

Pollutant (thousand tonnes)	Emissions emissions	% of total UK
CO	3,293	69
Black smoke and particulates	130	48
NOx	714	44
VOCs	473	27
CO2	31,200	22
SO2	12	1

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Diesel exhaust treatment requires an additional measure in the form of a particulate trap which can reduce emissions of particulate matter by up to 95%. The trap is a filter with a fine mesh. There is no problem in collecting the material - the "regeneration" of the trap poses the technical challenge. Carbon (soot) ignites at about 550 degrees centigrade. In normal operation this temperature would rarely be achieved in the exhaust pipe. Some traps use external means such as fuel burners or electrical heaters to raise the temperature to regenerate. In the U.K., the two established heavy-duty trap suppliers achieve a lower carbon ignition point (of around 260 degrees Centigrade) through catalytic action.

While road traffic emissions make an important contribution to urban background concentrations of NO_2 and dominate concentrations of NO_2 at the roadside, the results of the study by the Airborne Particles Expert Group (APEG) greatly increased the understanding of the source apportionment of particles in the UK, showing that this is far more complex than previously realised, with different sources contributing to different types of particles. There are three types of particles - primary, secondary and coarse. The fine particulate fraction ($PM_{2.5}$), which is believed to have the most damaging effects on health, is composed predominantly of primary and secondary particles. While traffic emissions account for a substantial proportion of primary particles, distant sources, predominantly non-transport, may make a substantial contribution to primary and secondary particles under certain weather conditions. Transport measures alone, therefore, would not be sufficient to eliminate the exceedences predicted for 2005, and other measures across Europe, predominantly non-transport, would be required. Further research is now planned to estimate the cost of reducing PM_{10} emissions from non-transport sources but the results will not be available for this first review.

Bulk Passenger Transportation

Buses, which are predominantly diesel powered, are generally recognised as an environmentally friendly form of transport, when one considers the number of car journeys needed to carry the equivalent number of passengers. A bus uses less fuel per person carried and hence produces less pollution than the number of cars it replaces. However, buses do contribute to air quality problems, particularly in cities, due to their higher concentrations in these areas. Improvements in the emission performance of buses are likely to be needed in the future.

Air transport is one of the world's fastest growing energy use sectors. Most international travel is by air and domestic air travel in developed countries is expanding. Furthermore, whilst per capita demand for air transport is currently very low in poor populous countries, it has the potential to grow considerably. Whilst historically noise has been the major environmental issue associated with airports and aircraft, local and global effects of aircraft emissions on air quality are beginning to dominate the environmental agenda. Although technological advances are helping to reduce emissions, the continued growth in emissions is expected to rise in line with predicted growth in air traffic movements.

Emissions can arise from different modes of aircraft operation, namely idle, taxi, take-off, approach and landing. The mode of operation puts differing demands on the aircraft engines resulting in fluctuating pollution emissions. For example carbon monoxide and hydrocarbons, which arise from incomplete or poor combustion, are generally largest during taxi / idle operations. (Many hydrocarbons are odorous; the typical airport smell of unburned and partially burned kerosene is testament to this.) Emissions of NO_x, however, are generated largely by the oxidation of atmospheric nitrogen in the combustion process. As such their production is proportional to the combustion temperature, and emissions of NO_x are therefore at their highest during the take-off phase when the engine is generally producing maximum power. Emissions of carbon dioxide are directly related to the amount of fuel burned. During the landing phase the combustion is delivering some 30% power; at such a setting NO_x is still an important pollutant, whilst CO and hydrocarbon emissions become increasingly important as the combustion thrust output falls.

Human Health Effects of Pollutants

One of the most common adverse health effects of breathing polluted air is asthma, which is a disease of the lungs in which the airways are unusually sensitive to a wide range of stimuli, including inhaled irritants and allergens. This results in obstruction to airflow which is episodic - at least in individuals with early or mild asthma - and which causes symptoms of tightness and wheeziness in the chest.

There has been an increase of about 50% in the prevalence of childhood asthma over the last 30 years, which corresponds to an increase in atopic diseases generally over this time. There has been at least a ten-fold increase in hospital admissions for asthma among children, which may partly reflect changes in medical practice.

Those opposed to the motor vehicle have been quick to point out that over the period during which there has been an increase in the incidence of asthma, emissions of coal smoke and sulphur dioxide have fallen markedly whereas those of oxides of nitrogen and volatile organic compounds from motor vehicles have increased. During this time emissions of particles from coal smoke have fallen, whilst those from diesel vehicles have increased.

However, whilst there is laboratory evidence that air pollution could potentially have a role in the initiation of asthma, there is no firm epidemiological or other evidence that this has occurred in the UK or elsewhere.

While there is some epidemiological evidence that air pollution may provoke acute asthma attacks or aggravate existing chronic asthma, the effect, if any, is generally small and the effect of air pollution appears to be relatively unimportant when compared with several other factors (e.g., infections and allergens) known to provoke asthma. Other factors which should also be taken into account include e.g. the increase in oil-seed rape production, a known asthma-inducer, it is also suspected that in our increasingly 'sanitised' society the body is becoming less effective at overcoming such health problems.

Although some epidemiological studies of different occupational cohorts have shown that the risk of lung cancer among workers classified as having been exposed to diesel exhaust is approximately 1.2 to 1.5 times the risk in those classified as unexposed there is still doubt concerning the validity of these findings. The lack of definitive exposure data for the occupationally exposed study populations precludes using the available epidemiologic data to develop quantitative estimates of cancer risk. When appropriate human information is not available, some policymakers have relied on the results of animal bioassays to estimate human risk. There are also considerable doubts over the validity of using rat bioassay data to characterize the potential human risk associated with ambient exposure to diesel emissions. The reason for this uncertainty is that the mechanism of lung tumour induction that appears to operate in rats continuously exposed to high concentrations of diesel exhaust and other particulate matter may not be relevant to most humans, who are exposed intermittently to levels of diesel exhaust particulate matter that are two or three orders of magnitude lower than those used in the rat bioassays. Also, as already discovered during the investigation of other materials, it appears that the rat is particularly predisposed to the development of such tumours, since similar studies involving other animals have not produced similar results. The development of unique markers of exposure to diesel emissions and a better understanding of the mechanisms of carcinogenesis would help to establish scientifically valid links between the lung cancers observed in laboratory animals and the human disease, thus improving the accuracy of cancer risk assessments.

In terms of identifying those population groups at most risk, whilst it has been popularly supposed that pedestrians and cyclists are the main victims of vehicle pollution, studies have shown that air quality inside cars on urban streets is often much poorer than it is just outside those cars. Manufacturers of vehicles at the luxury end of the market are now incorporating filtration systems into the fresh air intakes of air-conditioning systems to address this situation.

Researchers reviewed over 70 recent studies comparing the levels of the major vehicle-derived pollutants found inside and immediately outside motor vehicles. They also looked into exposure to air pollutants by

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travellers using different transport modes. The results clearly show that, in typical urban conditions, car occupants are often exposed to higher levels of all the main air pollutants emitted from motor vehicles than are pedestrians, cyclists and public transport users. Car drivers travel in a "tunnel" of pollutants, with the pollutants emitted from one vehicle ending up in the vehicle behind.

Passengers in larger public transport vehicles appear to be exposed to lower pollutant levels for primary pollutants than those in cars, but above those experienced by pedestrians and others towards the edge of the roadway.

Cyclists are potentially subject to higher personal exposure because of their elevated respiration rates, but nonetheless appear to suffer similar or lower exposures than motorists owing to their usually travelling close to the kerbside.

Contrary to popular belief, therefore, pedestrians generally experience the lowest exposures of any road users.

Emission Legislation

European Union emission regulations for new light duty vehicles (cars and light commercial vehicles) were originally specified in the Directive 70/220/EEC. This regulation was amended a number of times; some of the most important amendments include the Euro 1/2 standards, covered under Directives 93/59/EC (EC93) and 96/69/EC (EC96), and the most recent Euro 3/4 limits, covered by Directive 98/69/EC. The 2000/2005 standards were accompanied by an introduction of more stringent fuel quality rules that required minimum diesel cetane number of 51 (year 2000), maximum diesel sulphur content of 350 ppm in 2000 and 50 ppm in 2005, and maximum petrol (gasoline) sulphur content of 150 ppm in 2000 and 50 ppm in 2005.

The Euro 2-4 emission standards are different for diesel and gasoline vehicles. Diesels have lower CO standards but are allowed higher NO_x. Gasoline vehicles are exempted from PM standards. The standards for new cars are summarized in Table 2, the standards for light trucks in Table 3. Values listed in the tables are type approval emission limits (unless noted otherwise). Also the listed dates refer to new type approvals. The regulations additionally specify effective dates for first registration (entry into service), in most cases one year after the respective type approval date.

Table 2. Passenger Car Emission Standards

Table 2.a DIESEL EU Emission Standards for Passenger Cars, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.00	-	0.70	-	0.08
Euro 2, DI	1996.01[a]	1.00	-	0.90	-	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

†Values in brackets are conformity of production (COP) limits.
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)

Table 2.b PETROL (GASOLINE) EU Emission Standards for Passenger Cars, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.20	-	0.50	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.00	1.00	-	0.08	-

Table 3. Light Commercial Vehicle (LCV) Emission Standards

Table 3.a DIESEL N1 Class I < 1305 kg EU Emission Standards for LCVs, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1	1994.10	2.72	-	0.97	-	0.14
Euro 2	1998.01	1.00	-	0.60	-	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

Table 3.b DIESEL N1 Class II < 1305-1760 kg EU Emission Standards for LCVs, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1	1994.10	2.72	-	0.97	-	0.14
Euro 2	1998.01	1.00	-	0.60	-	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

Table 3.c DIESEL N1 Class III >1760 kg EU Emission Standards for LCVs, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1	1994.10	6.90	-	1.70	-	0.25
Euro 2	1998.01	1.35	-	1.30	-	0.20
Euro 3	2002.01	0.95	-	0.86	0.78	0.10
Euro 4	2006.01	0.74	-	0.46	0.39	0.06

Table 3.d PETROL (GASOLINE) N1 Class I < 1305 kg EU Emission Standards for LCVs, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro1	1994.10	2.72	-	0.97	-	-
Euro2	1998.01	2.20	-	0.50	-	-
Euro3	2000.01	2.30	0.20	-	0.15	-
Euro4	2005.01	1.00	0.10	-	0.08	-

Table 3.e PETROL (GASOLINE) N1 Class II 1305-1760 kg EU Emission Standards for LCVs, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1	1994.10	5.17	-	1.40	-	-
Euro 2	1998.01	4.00	-	0.65	-	-
Euro 3	2002.01	4.17	0.25	-	0.18	-
Euro 4	2006.01	1.81	0.13	-	0.10	-

Table 3.f PETROL (GASOLINE) N1 Class III >1760 kg EU Emission Standards for LCVs, g/km						
Tier	Year	CO	HC	$HC+NO_x$	Nox	PM
Euro 1	1994.10	6.90	- 1.70		-	-
Euro 2	1998.01	5.00	-	0.80	-	-
Euro 3	2002.01	5.22	0.29	-	0.21	-
Euro 4	2006.01	2.27	0.16	-	0.39	0.06

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* For Euro 1/2 the weight classes were Class I < 1250 kg, Class II 1250-1700 kg, Class III > 1700 kg.

Useful vehicle life for the purpose of emission regulations is 80,000 km through the Euro 3 stage, and 100,000 km beginning at the Euro 4 stage (2005).

The 2000/2005 regulations include several additional provisions, such as:

- EU Member States may introduce tax incentives for early introduction of 2005 compliant vehicles.
- Requirement for on-board emission diagnostics systems (OBD) phased-in between 2000 and 2005.
- Requirement for low temperature emission test (7°C) for gasoline vehicles effective 2002.

The role of the lubricant in reducing emissions

Vehicle designers are being required to achieve higher and higher standards of fuel efficiency, reduce vehicle emissions and increase vehicle service mileage intervals. Lubricants play an important role in the achievement of all of these requirements, which are all emissions-related, either directly or indirectly.

Lubricants can directly improve fuel economy, with consequent reductions in CO_2 emissions, in two ways:

Lower viscosity lubricants will reduce churning/pumping losses in the engine; gains here are especially evident during the 'warming-up' phase.

The incorporation of friction-reducing additives, often based on molybdenum, will also decrease frictional losses in the engine.

The use of lower viscosity oils, whilst simple enough in theory, presents in practice a number of problems for the lubricant formulator. In general, although lower viscosity oils are well capable of providing an adequate lubricant function in a system designed for their use, they are more volatile. This volatility causes an increase in oil consumption by evaporative losses via positive crankcase ventilation systems, which in turn increases emission levels and also the need for more frequent topping-up. Increased migration rates past the piston oil-control ring into the combustion zone again leads to increases in emissions. Progressive loss of the lighter components will also result in oil thickening, with consequent adverse effect on fuel consumption. In engines not designed for low viscosity oils, certain parts of the engine subject to high loads are likely to wear at an increased rate due to breakdown of the lubricant film, with the consequent transition from hydrodynamic to mixed/boundary lubrication conditions.

Since conventional mineral oils could not achieve the desired combination of low viscosity and low volatility, newer high-performance crankcase oils are now being formulated from synthetic fluids, such as polyalphaolefins (PAOs), or on a series of products known as 'unconventional base oils' or UCBOs. These latter products originate from crude oil, as do conventional mineral oils. However, their manufacture involves additional new refining techniques such as severe hydrocracking or wax isomerisation which re-arrange the molecular structure to such an extent that the finished product has properties more akin to those of a pure synthetic oil, although at about 50% of the cost.

The use of friction modifiers to reduce internal friction in the engine is becoming increasingly widespread, as the newer specifications for crankcase oils emanating from both the API and ACEA call for demonstrable and sustainable improvements in fuel utilisation efficiency compared with reference oils.

In addition to the above, lubricants have a number of less direct roles in reducing emissions. For example, in order that catalytic convertor efficiencies are maintained at their optimum levels for as long as possible, it is essential that exhaust gases do not contain substances which interfere with their operation. Although lead is one of the worst offenders in this respect, other elements can also have an adverse effect at sufficiently high concentration levels.

Phosphorus, for example, which is present in the commonly used anti-wear and anti-oxidant lubricant additive, zinc dialkyldithiophopshate (ZDDP), collects primarily at the catalyst face, with lesser amounts present over the remaining length of the catalyst, and adversely affects catalyst light-off performance. Reducing exposure of the catalyst to phosphorus can only be accomplished by reducing oil consumption and by reducing the phosphorus content in the lubricant. This in turn can cause problems in achieving the desired levels of component durability, friction reduction and extended drain intervals, since ZDDP is not readily replaceable. Additive technology is evolving to enable satisfactory lubricant performance even with reduced levels of phosphorus.

Also, there are many other current developments in the design of the vehicle powertrain including the newer sophisticated continuously-variable and infinitely-variable gearboxes, cooling-on-demand, engine cut-out when stationary, camless operation, etc., all of which are intended to improve fuel economy and all of which have implications for lubricant design.

In order to achieve continuing and sustainable improvements in emission reduction, it is therefore essential that the overall design philosophy incorporates lubricant design in addition to mechanical and fuel considerations.

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EUROPEAN BIODIESEL STANDARD DIN EN 14214 IN FORCE

The current national standard E DIN 51606 is to be replaced on publication of the European biodiesel standard DIN EN 14214 by the Deutsches Institut für Normung e. V. (DIN) (The German Standards Institute). Within the framework of several years of negotiations, car manufacturers, biodiesel producers and representatives from the oil industry have agreed on a Europe-wide minimum standard for biodiesel.

The European Quality Standard provides for a series of examples, whereby the rules are to be tightened and the oxidation stability requirement readopted. As a result, stricter demands are being placed on the production of biodiesel and quality control. According to the biodiesel producers, that are regrouped under the Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V. (AGQM) (Working Group for the Quality Management of Biodiesel), there is no problem ensuring that the oxidation stability requirement and the stricter conditions, particularly concerning transesterification quality, are met. Copies of the standard are available from Beuth-Verlag, Berlin.

LINK
www.agqm-biodiesel.de
www.beuth.de
www.ufop.de