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WEAR CHECK CONDITION MONITORING THROUGH OIL ANALYSIS

THE LOWDOWN ON LOWER EMISSIONS - Part 1

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The automotive industry in South Africa is largely focused at the moment on lowering vehicle exhaust emissions. This follows a global movement towards more stringent air emission control laws in man's attempt to slow down the destruction of our planet through global warming. So what is all the hype about? A basic understanding of the fundamentals of global warming in terms of the greenhouse effect is needed in order to understand the advances the automotive industry is implementing to combat dangerous exhaust emissions.

OUR ATMOSPHERE

Climate has always been the major factor in determining the activities and lifestyle of man. Over the last two centuries the activities of man have increasingly interfered with the climate on a global scale. This interference undoubtedly will affect man's lifestyle as well as his future existence on Earth.

The thin layer of gases that surrounds our planet is called the atmosphere. 99% of the atmosphere lies within 30 km of the Earth's surface. If we compare Earth and its atmosphere to an apple, the thin layer of air would be proportionally thinner than the apple peel.

The planets in our solar system vary greatly. Earth is unique because it is the only planet with atmosphere rich in oxygen. The atmosphere contains several different gases. Dry air contains mostly nitrogen (78%). Most of the remainder is oxygen and the rest is made up of very small amounts of carbon dioxide, argon and other noble gases, and water vapour.

Gas	Percentage
Nitrogen	78
Oxygen	21
Argon	1 (just less)
Carbon dioxide	0,04
Neon, krypton, xenon, water vapour	Very small amounts

Make-up of air in atmosphere

Nitrogen is a very unreactive (inert) gas. Living organisms need nitrogen to build protein. The inert nitrogen in the atmosphere is changed to accessible nitrogen by various natural chemical and biological processes. Oxygen is a reactive gas and, during a reaction with other elements, oxides are formed. This process is known as oxidation. Respiration in living organisms and combustion of fuels are two examples of oxidation; these are both life-sustaining processes on Earth. Only about 0,04% of the atmosphere consists of carbon dioxide. Yet without this gas, there would be no plant and animal life on Earth. Plants use carbon dioxide to form glucose during the process of photosynthesis. Animals feed on these plants to obtain glucose which they use as an energy source.

The atmosphere is broken up into different layers. The troposphere is the thinnest layer of the atmosphere and contains about 80% of the total mass of air and nearly all the

atmospheric water vapour. It is also here where all the weather events occur – rain, lightning, storms and hurricanes. It extends from the Earth's surface to about 10 -16 km, depending on the latitude. The process of photosynthesis takes place in the troposphere.

ATMOSPHERIC POLLUTION

We know that the Earth's atmosphere has undergone major changes in the past, but that its chemistry has been more or less constant since the beginning of humankind. The chemistry is now changing. The amount of methane in the atmosphere is increasing at an alarming rate of more than 1% per year. The concentration of carbon dioxide has more than doubled in the last 250 years and seems to be increasing at an exponential rate. The troposphere is closest to Earth's surface, and it is therefore the part of the atmosphere which is most affected by human activities.

In South Africa atmospheric pollution is a major environmental problem. We derive 75% of our energy from coal, and most air pollution problems are associated with coal burning. There are three main types of pollution that affect the troposphere: air pollution, acid rain (and ash pollution), and the greenhouse effect.

ACID RAIN

Normal rain is slightly acidic. This is because carbon dioxide in the air dissolves in raindrops to form carbonic acid, which is a weak acid. Sulphur dioxide, and to a lesser degree nitrogen oxides, can dissolve in rainwater to form acid rain. Acid rain can have a pH of 4 or lower and can cause widespread damage. Most power stations burn coal or oil to generate electricity. Both these fuels contain sulphur and during the combustion sulphur dioxide is formed. Nitrogen oxides are also produced in power stations as well as the engines of motor vehicles. Dissolved in water these gases can form nitrous acid and nitric acid. Damage caused by acid rain is difficult and expensive to rectify. The best solution is to prevent acid rain in the first place. This is being done by lowering fuel sulphur levels.

GREENHOUSE EFFECT

It is thought that human activities over the past century may have disturbed the delicate balance of Earth. The thermal balance is the ratio of the amount of radiation energy that Earth receives from the sun to the amount of infrared energy radiated back into space. Gases such as water vapour, methane and carbon dioxide, absorb the energy radiated by Earth. This heats up the atmosphere and keeps Earth warm. If this was not the case, the average temperature on the surface of the Earth would be -18°C. This warming effect is called the greenhouse effect.

AIR POLLUTION

One of the main causes of air pollution is the release of unburned hydrocarbon molecules, nitrogen oxide and other toxic by-products during the combustion of petroleum products in motor vehicle engines. Petrochemical smog is a hazy, brownish layer that forms over cities where there is a large amount of traffic. Such smog has become a major irritant to humans, animals and plants. For petrochemical smog to occur, bright sunlight, still air and temperature inversion are also required.

Note: Close to Earth's surface, air temperature normally decreases with height above ground level. With temperature inversion, a layer of cool air becomes trapped under less dense, warmer air. In this still air, pollutants from car exhausts build up.

INCOMPLETE COMBUSTION

The natural by-products of stoichiometric combustion are water (H_2O) and carbon dioxide (CO_2). But this is only true if complete combustion takes place which is virtually impossible to achieve. In real life situations incomplete combustion takes place in an engine producing a number of major pollutants. These are hydrocarbons, carbon monoxide (CO), various oxides of nitrogen (NOx), and particulates. Sulphur, lead and phosphor are minor pollutants.

Note: Fossil fuels are hydrocarbon fuels. Hydrocarbons are organic compounds which contain only carbon (C) and hydrogen (H). Hydrocarbon fuels consist mainly of various combinations of carbon and hydrogen as well as small quantities of sulphur, lead and phosphorous.

Incomplete fuel combustion is represented by the equation:

$2C_8H_{18}$ (l) + $17O_2$ (g) ⇨ $9,2CO_2$ (g) + $8,8H_2O$ (g) + $9,2H_2$ (g) + $6,8CO$ (g)

HYDROCARBONS OR VOLATILE ORGANIC COMPOUNDS (VOCs)

Hydrocarbons or volatile organic compounds (VOCs) are produced in two ways. Firstly as a result of large fuel molecules cracking up during combustion and not getting a chance to complete the combustion. Secondly as a result of unburned fuel. Hydrocarbons enter the atmosphere via the exhaust and evaporate. They are irritants, produce unpleasant smells and some are carcinogenic. Sunlight then breaks these hydrocarbons down to form oxidants, which react with oxides of nitrogen (NOx) to cause ground level ozone (O_3), a major component of smog. Hydrocarbons also come from the engine lubricating oil.

NITROGEN OXIDES (NOx)

Temperatures inside vehicle engines are high, and atmospheric nitrogen reacts with oxygen (both contained in the air drawn into the combustion chamber) to form nitrogen monoxide (NO).

N_2 (g) + O_2 (g) ⇨ 2NO (g)

This nitrogen monoxide then enters the atmosphere, via the exhaust, where it quickly oxidises to form brown nitrogen dioxide (NO_2).

2NO (g) + O_2 (g) ⇨ $2NO_2$ (g)

Sunlight causes the decomposition of NO_2 into NO and O.

NO_2 (g) ⇨ NO (g) + O (g)

Atomic oxygen (O) is highly reactive and can initiate a number of reactions, one of which is the formation of ozone (O_3).

O (g) + O_2 (g) ⇨ O_3 (g)

Ozone is a highly reactive substance which can further combine with unburned hydrocarbons in the air. These substances eventually condense into small droplets of liquid in the air, called aerosol, which scatter sunlight to make the air look hazy.

CARBON MONOXIDE (CO)

Carbon monoxide is a common air pollutant in the industrialised world. It is produced when fossil fuels are incompletely burnt. Carbon monoxide is poisonous at levels of only 0,1 %. All living organisms rely on oxygen for respiration. Haemoglobin in our red blood cells carries oxygen to all the cells in our bodies. Carbon monoxide is attracted to haemoglobin over 200 times more strongly than oxygen. In the blood, carbon monoxide prevents haemoglobin from transporting oxygen. This leads to dizziness, headaches and even death.

LEAD COMPOUNDS

Lead compounds are the most toxic heavy-metal pollutants in the air. Lead compounds are found in leaded motor vehicle petrol, and people living near busy roads can have high levels of lead in their blood. Lead poisoning causes nervous disorders and learning disabilities in children. The change to unleaded petrol has reduced this health hazard dramatically.

SULPHUR COMPOUNDS

Sulphur compounds are produced during the combustion process of diesel fuel vehicles. Sulphur dioxide (SO_2) is generated from the sulphur present in diesel fuel. The concentration of SO_2 present in the exhaust gas depends on the sulphur content of the fuel. Sulphur dioxide is a colourless, toxic gas with a characteristic, irritating odour. Oxidation of sulphur dioxide produces sulphur trioxide which in turn produces sulphuric acid. Sulphuric acid is responsible for sulphate particulate matter emissions. Sulphur oxides are the major cause of acid rain and therefore have a profound impact on the environment.

PARTICULATES

Particulates are solid carbon soot particles that are generated during the combustion process of a diesel engine when diesel fuel combusts, and when lubricating oil, on the components which take part in combustion, vaporises. The lower temperature in the exhaust then causes all sorts of components from the fuel and oil to condense on these carbon soot particles, making them a lot nastier for humans and other life forms than if they were pure carbon.

Pollutant	Effect
Hydrocarbons/ volatile organic compounds	Cancer, respiratory effects
Nitrogen oxides (NOx)	Respiratory system, lungs
Carbon monoxide	Circulatory system, heart, brain
Lead compounds	Nervous system, damage to foetuses and infants, learning deficits and lowered IQ
Sulphur compounds	Airways, lungs, increase risk of colds, bronchitis, asthma
Particulates	Lungs, potential effects on the heart, premature death

Effects of different pollutants

EMISSION CONTROL LAWS

It is now clear that pollution from vehicle exhaust emissions is a threat to the quality of life and general wellbeing of all on Earth. In order to move towards a cleaner environment and therefore healthier life the global movement is towards cleaner exhaust emissions. Emissions from vehicles has become a problem in South Africa, as in the rest of the industrialised world, due to a steady increase in the number of vehicles on the roads and an increase in the distance driven by these vehicles. Add to this the fact that a high percentage of these vehicles are either badly maintained, old or both and the problem amplifies. Vehicles not equipped with emission control devices can also emit more than ten times the emissions of equivalent vehicles in emissions regulated markets. It therefore became necessary for the South African government to intervene by formalising emissions standards applicable to vehicles, and standards for vehicle fuels.

The Department of Minerals and Energy (DME) and the Department of Environmental Affairs and Tourism (DEAT) collaborated to prepare a strategy for reducing harmful exhaust emissions. This strategy attempted to balance conflicting objectives and priorities such as affordability of vehicles, the economics of fuel production and the cost of fuel and air quality standards. This strategy was then used to promulgate the National Environmental Management: Air Quality Act, 2004 which enables authorities to effectively enforce the objectives of the strategy. The backbone of the strategy is the implementation of clearly defined standards for vehicle exhaust emissions and appropriate fuel specification. This is based on European ECE regulations, ECE Regulation No. 83 (ECE R83) and its various amendments.

The proposed timetable for the implementation of the emission control laws are summarised in the tables below. These have been obtained from the final draft of the Joint Implementation Strategy for the Control of Exhaust Emissions from Road-Going Vehicles in The Republic of South Africa (Notice 3324 of 2003).

Passenger vehicles & light delivery vehicles (GVM < 3,5 tonnes)	
Phase 1	
January 2004	**ECE R83 Euro 1:** All homologated vehicles
January 2005	**ECE R83 Euro 2:** All newly homologated vehicles
January 2006	**ECE R83 Euro 2:** All newly manufactured vehicles
Phase 2	
January 2010	**ECE R83 Euro 4:** All newly homologated vehicles
January 2012	**ECE R83 Euro 4:** All newly manufactured vehicles

Implementation dates for passenger vehicles and light commercial vehicles (GVM < 3,5 tonnes) - positive ignition and diesel vehicles

Heavy vehicles (GVM > 3,5 tonnes)	
January 2005	**ECE R49-02 Euro 2:** All newly homologated vehicles (gas-fuelled vehicles exempt)
January 2006	**ECE R49-02 Euro 2:** All new vehicles (gas-fuelled vehicles exempt)
January 2010	**ECE R49-02 Euro 4:** All newly homologated vehicles (gas-fuelled vehicles exempt)
January 2012	**ECE R49-02 Euro 4:** All new vehicles (gas-fuelled vehicles exempt)

Implementation dates for heavy vehicles (GVM > 3,5 tonnes)

Parameter	Unit		RSA 2003	RSA 2006	RSA 2008	RSA 2010+
Petrol						
Octane		**Coast**	97L 95/97 ULP	91/95 ULP	91/95 ULP	81/95 ULP
		Inland	93L 93 ULP	91/95 ULP	91/95 ULP	91/95 ULP
Reid vapour pressure (RVP)	Kpa		W8 O/S 65*	65	tbd	tbd
Aromatics	% v/v		42	42	42	tbd
Benzene	% v/v		3	3	3	tbd
Sulphur (max)	ppm		500-800	500	500	50
Lead (max)	g/l		0,4	nil	nil	Nil
Metal additives	ppm		18,0	***	***	***
(MMT)						
Ethers & selected alcohols	mm		<10% ULP	2,70%	tbd	tbd
Diesel						
Sulphur	ppm		500	500	50	50

** Winter and summer levels on coast*
**** Will potentially depend on outcome of study*
tbd: To be determined

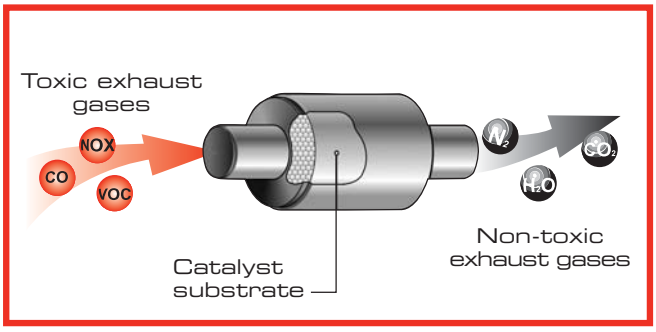
Table of fuel specifications for South Africa

CLEANER VEHICLE EXHAUST EMISSIONS

In order to conform to these laws vehicle engines need to produce cleaner exhaust emissions. For an engine to produce cleaner emissions it has firstly to be designed to produce less harmful by-products. Secondly a way had to be found to convert these harmful products into less harmful substances before they entered the atmosphere via the vehicle's exhaust. Therefore vehicle manufacturers had to make many refinements to engines and fuel systems and have also developed a device called a catalytic converter, which treats the exhaust emissions before they leave the vehicle and removes a lot of the pollution.

In Europe and the USA catalytic converters have been in use for many years and are fitted to 90% of light-duty vehicles. They have destroyed billions of tonnes of engine exhaust gas pollution. South Africa is now following this trend and most new passenger vehicle models are fitted with catalytic converters. New vehicles introduced from February 2005 have to meet an emission level which can only be achieved by fitting a catalytic converter. By 2008 all new petrol vehicles will have to be fitted with catalytic converters. This will apply to imported as well as locally manufactured vehicles. Catalytic converters reduce a vehicle's toxic exhaust emissions by approximately 90%.

Most modern cars are fitted with three-way catalytic converters. "Three-way" refers to the three regulated emissions it helps to reduce, i.e. CO, NOx and VOCs / hydrocarbons.



Catalytic Converter

Earlier it was shown how nitrogen monoxide (NO) forms at very high temperatures inside the engine (about 1800°C). Nitrogen monoxide is then oxidised to brown nitrogen dioxide (NO_2) when it mixes with air. It was also shown that incomplete combustion in an engine produces the harmful by-products carbon monoxide (CO) and hydrocarbons (CxHy) / VOCs. The catalytic converter helps to promote the following overall reactions:

The oxidation of carbon monoxide to carbon dioxide:

$$2CO(g) + O_2(g) \Rightarrow 2CO_2(g)$$

The reduction of nitrogen monoxide back to nitrogen:

$$2NO(g) + 2CO(g) \Rightarrow N_2(g) + 2CO_2(g)$$

The oxidation of unreacted hydrocarbons to water and carbon dioxide, for example:

$$2C_8H_{18}(l) + 25O_2(g) \Rightarrow 16CO_2(g) + 18H_2O(g)$$

The catalytic converter is fitted into the exhaust system of an engine. It looks like a metal canister and has no moving parts. The inside of the converter has a ceramic honeycomb structure / ceramic bead material which provides a large surface area and is covered with a catalyst on which the reaction takes place. This catalyst is expensive as it is made of alloys of platinum, rhodium and palladium. As the pollutants (CO, NO, NO_2 and unburned hydrocarbons) pass through the channels of the converter, they adsorb to the surface of the catalyst. Here the chemical reactions take place, followed by desorption of the products which are released back into the exhaust stream. The clean exhaust fumes then flow out of the tail pipe.

The catalytic converter therefore reduces polluting carbon and nitrogen oxides and completes the oxidation of unburned hydrocarbon fuel. Thus photochemical smog is prevented from forming. Catalytic converters can only be used with unleaded petrol as the presence of lead poisons the catalyst and prevents it from working. Catalysts are designed to maintain their pollutant destruction function for the life of the vehicle but it is easy to render a converter useless. It gets degraded by excess heat, dirt and poisoning of the active material and there are therefore many ways to reduce the life of a catalytic converter, i.e. having a badly-tuned engine that will promote excessive lean or rich conditions, bad starting, misfiring, push-starting an engine or testing for a spark by removing one of the plug leads. All of these will generate excessive heat inside the converter.

Also lead and sulphur from the fuel, as well as zinc, phosphorous, antimony, calcium and magnesium from the oil, will coat the catalyst and reduce its efficiency.

Modern diesel engines use a catalytic converter that is similar to a petrol engine one but they also need a particulate filter. There are many designs but they all essentially trap the particles and remove them from the exhaust gas stream. Modern units are able to remove just over 90% of particulate matter. The particle filter will get blocked and needs to be cleaned continuously, or regenerated from time to time. This is done via a continuous or passive system (a catalyst at the front of the filter generates nitrogen dioxide from nitrogen oxide in the exhaust and uses this to reduce the carbon to carbon dioxide), or an active system (which uses oxygen to burn the carbon away). The active system requires the temperature inside the converter to be raised above 600°C by injecting diesel fuel into the exhaust system whenever a sensor tells the control unit that the filter needs it.

New diesel engine technology combines an oxidising catalyst, a particulate filter, and a storage catalytic converter that injects ammonia into the gas, converting the nitrogen oxides into harmless nitrogen. The ammonia is obtained from a substance commonly known as urea, stored in a separate tank that is refilled periodically.

So a lot has been done to ensure vehicles are equipped to be able to emit cleaner exhaust gases. But the onus is still on the owner of the vehicle to maintain the vehicle sufficiently to ensure it, and all its components, operate at their peak. The scope of what the South African government can do in terms of emission control is limited as a crucial ingredient is buy-in from citizens and vehicle owners, and enforcement of the emission laws. Education is also the key and a cleaner, healthier life can only be encouraged by education and determination by the people who matter – ourselves.

Look out for WearCheck's next Technical Bulletin which will take a closer look at catalytic converters, new engine technology and new fuel technology.

Michelle Allis is a diagnostician at WearCheck Africa

GLOSSARY

Euro 1	Emission Standards effective 1 January 1992
Euro 2	Emission Standards effective 1 January 1997
Euro 3	Emission Standards effective 1 January 2000
Euro 4	Emission Standards effective 1 January 2005
Euro 5	Emission Standards effective 1 January 2008
Homologated	approved vehicles
Newly homologated	new approved vehicles
Catalyst	a substance that changes, especially increases, the rate of a chemical reaction but itself remains chemically unchanged.
Adsorb	to take up and hold onto

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Notice 3324 of 2003 Final Draft - Joint Implementation Strategy for the Control of Exhaust Emissions From Road-Going Vehicles in the Republic of South Africa.

Grade 11 Physical Sciences Study and Master Textbook

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