WEARCHECK AFRICA
A member of the Set Point group
TECHNICAL BULLETIN ISSUE 42

THE LOWDOWN ON LOWER EMISSIONS - Part 2

by Michelle Allis, BSc Eng (Mech)

Michelle Allis

It was seen in the last Technical Bulletin that, in order to reduce our effect on the environment due to harmful vehicular exhaust emissions, we need to ensure a reduction of the emissions. This is now reality due to the new laws being implemented around the world. So what is being done to ensure this happens and what part do we, as the consumer and concerned citizen, play in all this?

The ideal scenario would be to replace all vehicles with so-called 'green' vehicles but for obvious reasons this is not an option anywhere in the world.

'Green' vehicles

Alternative technology 'green' vehicles are clean-energy vehicles that use energy sources other than petroleum, such as compressed natural gas, electricity, methanol, hydrogen or solar energy. Many clean-energy vehicles have been developed and some are already in operation, but they still present certain problems such as short travelling ranges and high operational costs. For this reason, they are at present used only for a limited number of applications and within limited areas.

So the real challenge for engineers is in designing cleaner petroleum-fuelled engines to reduce vehicular emissions without sacrificing engine performance or reliability or complicating maintenance too much. The emissions produced by a vehicle fall into three basic categories:

- tailpipe or exhaust emissions
- evaporative emissions
- life cycle emissions

This Technical Bulletin will discuss these different categories of vehicular emissions and the technological advances engineered to combat them, and then look at the testing of exhaust emissions in order to ascertain whether a vehicle meets the required emission control laws dealt with in the last bulletin.

TAILPIPE/ EXHAUST EMISSIONS

These are the emissions that most people think of as vehicle air pollution. They are hydrocarbons, nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide (CO_2). These emissions can be lowered by:

- increasing engine efficiency
- increasing vehicle efficiency
- increasing driving efficiency
- cleaning up emissions

INCREASING ENGINE EFFICIENCY

Engine efficiency has been improved with progress in electronic ignition, fuel injection systems and electronic control units.

Mechanical ignition systems require regular adjustment to compensate for wear. The opening of the contact breakers, which are responsible for spark/ignition timing, is subject to mechanical variations. In an **electronic ignition**, the lack of moving parts compared with the mechanical system leads to extremely accurate spark timings, resulting in improved combustion and emission control.

Fuel injection systems increase fuel efficiency, increase power output, ensure smooth driveability and lower emissions. Modern electronic fuel injection systems meter fuel very accurately and precisely, and use closed-loop fuel injection quality control based on feedback from an oxygen sensor. This enables fuel injected engines to produce less air

WEARCHECK CONDITION MONITORING THROUGH OIL ANALYSIS

pollutants than comparable carburetted engines. Properly designed fuel injection systems can react rapidly to changing inputs such as sudden throttle movements, and will control the amount of fuel injected to match the engine's needs across a wide range of operating conditions such as engine load, ambient air temperature, engine temperature, fuel octane level and altitude.

An **electronic control unit (ECU)** controls various aspects of an internal combustion engine's operation. The simplest ECUs control only the quantity of fuel injected into each cylinder and each engine cycle, while more advanced ECUs, found on most modern vehicles, also control the ignition timing, variable valve timing, the level of boost maintained by the turbocharger, and other peripherals. ECUs monitor the engine through sensors such as a throttle position sensor, air temperature sensor or oxygen sensor, and therefore determine the various parameters as discussed above.

A relatively recent application of engine control is the use of the precisely timed injection and ignition to start an engine without the use of a starter motor. Such a static-start engine would provide the efficiency and pollution reduction improvements of a mild hybrid-electric drive but without the expense and complexity of an oversized starter motor.

A special category of ECUs are those which are programmable. They do not have a fixed behaviour but can be programmed by the user. Programmable ECUs are required where significant aftermarket modifications have been made to a vehicle's engine. The controllable parameters can be programmed/mapped with a laptop connected using a serial or USB cable, while the engine is running and adjusted according to the values obtained while monitoring the exhaust emissions. Some of the parameters that are often mappable are ignition, rev limit, water temperature correction, transient fuelling, low fuel pressure modifier, closed loop lambda and variable cam timing.

INCREASING VEHICLE EFFICIENCY

Exhaust emissions are also lowered by increasing vehicle efficiency through a number of different technological advances. These are things such as lightweight vehicle design, minimised air resistance, reduced rolling resistance, improved powertrain efficiency and regenerative braking.

INCREASING DRIVING EFFICIENCY

Significant reduction in emissions also results from increased driving efficiency through improved driving technique, unobstructed traffic conditions, cruising at an optimum speed for the vehicle, and reducing the number of cold starts.

Advances in engine and vehicle technology continually reduce the amount of pollutants generated but this is generally considered insufficient to meet emission reduction goals. Therefore, technologies to react with and clean up the remaining emissions have long been an essential part of emissions control.

CLEANING UP EMISSIONS

The different technologies engineered for the purpose of cleaning up the emissions are:

- secondary air injection
- exhaust gas recirculation
- particulate traps/filters
- selective catalytic reduction
- catalytic converters

Combustion gases that enter the exhaust manifold are not completely burned and would continue to burn if not limited by the amount of oxygen in the exhaust system. To decrease the level of emissions emitted from the tailpipe/exhaust pipe, the **secondary air injection** system is used to inject air into the exhaust flow, thereby allowing combustion to continue well into the exhaust system. This prolonged combustion (oxidation) period helps to lower the levels of hydrocarbons (HC) and carbon monoxide (CO) emissions that are forwarded to the catalytic converter. Additional air in the exhaust system also ensures that an adequate supply of oxygen is provided to the converter for catalyst oxidation. This technology is not used so much these days due to cleaner burning engines and more efficient catalytic converters.

Most modern engines have an **exhaust gas recirculation** (EGR) system. A valve is positioned between the exhaust and intake manifolds with its sole purpose being to reduce nitrogen oxide (NOx) emissions. NOx is formed in high concentrations whenever combustion temperatures exceed about 2500°F (1371°C). The EGR system recirculates small amounts of exhaust gases into the intake manifold where it mixes with the incoming air/fuel charge. By diluting the air/fuel mixture under these conditions, peak combustion temperatures and pressures are reduced, resulting in an overall reduction of NOx emissions. Some vehicle manufacturers have been able to do away with EGR systems as their engines are able to meet emission specifications without them. In some cases the valve timing has been set to hold some exhaust gases in the combustion chamber after the exhaust stroke to perform a similar function to EGR.

One of the specified controlled vehicular emissions relating to diesel fuelled vehicles is particulate matter (PM). These emissions are controlled by using **particulate traps (filters)**. As a general rule particulate traps are only fitted to diesel vehicles over 7,5 tonnes and to vehicles of Euro I, II, and III emission standards, although they are now becoming available for smaller diesel vehicles. New vehicles can also be fitted with traps and they are sometimes offered as an option on new diesel cars. Particulate traps can achieve a reduction in carbon monoxide (CO) and hydrocarbon (HC) emissions of 80% and over 90% in particulate matter. A particulate trap is a ceramic filter within the exhaust system of a diesel engine that captures particulates before they can enter the atmosphere.

The captured particles are burnt off during the operation of the vehicle using advanced control systems, catalytic coatings or fuel-borne catalysts (FBCs). If the captured PM is not removed, the filter will clog. Combinations of FBCs with other systems provide the most reliable regeneration. Ash residue accumulates in particulate traps and needs to be removed through regular maintenance.

Another technique used to reduce diesel vehicle emissions is **selective catalytic reduction (SCR)** which is a versatile emission reduction technology that can be used on many types of diesel vehicles but is best suited to larger vehicles, due to the need for a small separate tank of chemical reactant. SCR uses a reductant (ammonia or urea), which is injected into the exhaust gas to help reduce NOx emissions, over a catalyst. Some systems also use a particulate trap to further reduce emissions. It has the potential to reduce NOx emissions by between 50% and 90%, although this will be dependent on the duty cycle as the system is extremely temperature dependent. Some reduction of particulate matter is also achieved, even if a particulate trap is not fitted.

The last but certainly not least important device used to clean up vehicular emissions is the **catalytic converter**. The workings thereof have been discussed in the last Technical Bulletin but to recap, a catalytic converter is placed in-line with the exhaust system and converts various emissions into less harmful ones, generally using a combination of platinum, palladium and rhodium as catalysts.

Catalyst operating efficiency is greatly affected by two factors: operating temperature and feed gas composition. The catalyst begins to operate at around 288°C. However, efficient purification does not take place until the catalyst reaches at least 400°C. Also the converter feed gases (engine-out exhaust gases) must alternate rapidly between high CO content, to reduce NOx emissions, and high O_2 content, to oxidise HC and CO emissions. Some engines contain closed-loop control systems on their catalytic converter system. This ensures that the catalytic converter obtains the feed gas it needs. The closed loop control system is designed to rapidly alternate the air/fuel ratio slightly rich and slightly lean stoichiometry. By doing this, the carbon monoxide (CO) and oxygen (O_2) content of the exhaust gas also alternates with the air/fuel ratio. This precise control requires accurate feedback information provided from the exhaust oxygen sensor. A catalytic converter is usually designed to last the lifetime of the vehicle it is installed in. If it does fail it is usually a symptom of another problem. This problem must be identified and repaired or the new converter will fail in the same manner. Some common causes of catalytic converter failure are:

AN OUT OF TUNE ENGINE

An out of tune engine, due to improper air/fuel mixture, misfiring cylinders, faulty engine sensors, incorrect ignition timing, etc., can damage the catalytic converter.

EXCESS FUEL OVERHEATING THE CATALYTIC CONVERTER

An engine that is performing at peak efficiency will burn all the fuel in the combustion chamber during the combustion process. Unburned or excess fuel that is allowed to enter the exhaust system contacts the hot core of the converter and will ignite. This will cause temperatures to constantly rise above the designed operating temperature until the core of the converter will actually melt.

OIL OR COOLANT ENTERING THE EXHAUST

When oil or coolant enters the exhaust system and contacts the hot core of the converter, the oil and coolant will burn off and leave carbon deposits. These carbon deposits will coat the core of the converter, thus reducing the catalytic converter's ability to do its job. As the deposits continue to accumulate, the pores in the ceramic catalyst will become restricted and block exhaust flow through the exhaust system. The resulting increased back pressure will result in a loss of power and overheated engine components.

MALFUNCTIONING OXYGEN SENSOR

This can cause a too rich or too lean fuel condition. A rich condition will cause the converter to overheat and melt down from the unburned fuel being ignited while a lean condition can result in a misfire that can lead to the same result. Oxygen sensors can wear out and need to be changed according to the manufacturer's recommendation.

BROKEN EXHAUST HANGERS OR MISALIGNED EXHAUST

An exhaust system that is misaligned or allowed to rattle will cause the fragile ceramic catalyst inside the converter to break apart. When the core breaks or becomes loose in the converter, the brittle ceramic catalyst will continue to break up into smaller pieces that will eventually block the flow of the exhaust. This increased back pressure will lead to loss of power and heat build-up.

LEADED FUEL

Even as little as one tank full of leaded fuel may coat the catalyst element and render the converter useless.

SILICON

Silicon from sealants or engine coolants that leak into the exhaust may also coat the catalyst and render it useless.

THERMAL SHOCK

This occurs when a hot converter is quickly exposed to cold temperature (snow or cold fuel), causing it to physically distort and eventually disintegrate.

EVAPORATIVE EMISSIONS

Now we have dealt with the first category of vehicular emissions – tailpipe or exhaust emissions - it is time to move onto the next category, evaporative emissions.

A large portion of all hydrocarbon (HC) emissions from a vehicle originate from evaporative sources. The reduction of evaporative emissions includes the capturing and disposal of fuel vapours (normally created in the fuel system) and refuelling emissions, thereby preventing their escape to the atmosphere.

Within the vehicle, fuel vapours from the fuel tank are channelled through canisters containing activated carbon instead of being vented to the atmosphere. These are known as carbon canisters. The vapours are adsorbed within the canister, which then feeds into the inlet manifold of the engine. When the vehicle is running, the vapours desorb from the carbon, are drawn into the engine and burned.

In order to reduce refuelling emissions, most modern vehicles have tank filler necks that have a spring-loaded door and are only large enough for the tip of the nozzle. This prevents vapour leakage when the filler cap is removed, and also prevents a vehicle that is fitted with a catalytic converter from being refuelled with leaded fuel (although leaded fuel is no longer available).

LIFE CYCLE EMISSIONS

These emissions are not often thought of when considering vehicular related emissions. They are the emissions associated with the manufacturing, maintenance and disposal of the vehicle, and include such items as:

- manufacturing plant power requirements
- volatile solvents utilised in the manufacturing process (paint finishes, etc.)
- out gassing of synthetic materials utilised to reduce weight and simplify manufacturing
- maintenance requirements such as oil and filter changes, battery replacement, etc.
- disposal requirements including contaminated lubricants, tyres, heavy metals and landfill

As they have no relation to the actual operation of the vehicle they will not be discussed further.

EMISSIONS TESTING

So far we have discussed how harmful exhaust emissions are produced during combustion and what is being done to reduce these emissions. A vehicle's emissions can be tested to ensure compliance with the new emission control laws or to diagnose driveability concerns. The exhaust emissions of a vehicle are tested using an emission analyser. Even though mandatory testing is not being undertaken by the authorities in South Africa yet, it is still useful to know about emissions testing as the problems that often cause emission failures cause a variety of driveability and performance complaints.

Some inspection programs around the world also require visual checks of emissions-related equipment for evidence of tampering or damage. In the USA, the EPA (US Environmental Protection Agency) introduced the IM240 test program. Around 35 states have phased in I/M (inspection/maintenance) criteria modelled on the California Air Resources Board's emission testing standard. The IM240 test program checks for oxides of nitrogen (NOx) emissions as well as total emissions in grams per mile as the vehicle is run at various speeds and loads on a dynamometer. IM240 programs also require checking of the integrity of the fuel system for air leaks (evaporative emissions) and the flow capacity of the charcoal canister purge valve.

The readings obtained from an exhaust gas analyser depend on the type of analyser used. Though a good technician can often diagnose and repair emission problems without having to actually check tailpipe emissions, it is becoming increasingly necessary today to have an infrared exhaust analyser with at least three gas but preferably four or five gas capability. Presently, shop grade analysers are capable of measuring as little as two exhaust gases, HC and CO, to as many as five. These five gases measured by the latest technology exhaust analysers are: HC, CO, CO_2, O_2 and NOx. Even though CO_2 and O_2 are not pollutants, (CO_2 is a greenhouse gas though), they are useful to measure for diagnostic purposes.

CAUSES OF EXCESSIVE EXHAUST EMISSIONS

The cut points for acceptable HC and CO levels are generally based on the emission standards that a vehicle was required to meet when it was new, so older vehicles have more lenient emission standards than new ones. See Chart 1 below.

Chart 1: Emissions cut point chart

Model year	Typical cut points		Well-tuned engine	
	CO%	HC ppm	CO%	HC ppm
Pre 1968	7,5 - 12,5	750 - 2000	2,0 - 3,0	250 - 500
1969 - 1970	7,0 - 11,0	650 - 1250	1,5 - 2,5	200 - 300
1971 - 1974	5,0 - 9,0	425 - 1200	1,0 - 1,5	100 - 200
1975 - 1979	3.0 - 6,5	300 - 650	0,5 - 1,0	50 - 100
1980	1,5 - 3,5	275 - 600	0,3 - 1,0	50 - 100
1981 - 1993	1,0 - 2,5	200 - 300	0,0 - 0,5	10 - 50
1994 and up	1,0 - 1,5	50 - 100	0,0 - 0,2	02/20/08

(Please be aware that this is based on American standards.)

EXCESSIVE HC, CO AND NOx EMISSIONS

High or excessive hydrocarbon (HC) emissions are most commonly caused by engine misfires. High or excessive carbon monoxide (CO) levels are caused by anything that can make the air/fuel mixture richer than "ideal". Excessive oxides of nitrogen (NOx) can be caused by anything that makes combustion temperatures rise. Chart 2 below gives a list of problems which could cause high HC, CO, NOx levels on fuel injected vehicles. There may be some less likely causes but these are the most common ones.

Chart 2: Causes of excessive HC, CO, NOx

Hydrocarbons	Carbon monoxide	Nitrogen oxides
Ignition system failures • faulty ignition secondary component • faulty individual primary circuit on distributorless ignition system • weak coil output due to coil or primary circuit problem	Excessive fuel pressure at the injector(s)	Cooling system problems: • insufficient radiator airflow • low coolant level • poor cooling fan operation • thermostat stuck closed or restricted • internal radiator restriction
Excessively lean air/fuel mixture • leaky intake manifold gasket • worn throttle shaft	Leaking fuel injector(s)	Excessively lean air/fuel mixture • leaky intake manifold gasket • worn throttle shaft
Excessive EGR dilution • EGR valve stuck open or excessive EGR flow rate • EGR modulator bleed plugged	Ruptured fuel pressure regulator diaphragm	Closed loop control system incorrectly shifted lean
Restricted or plugged fuel injector(s)	Loaded/malfunctioning EVAP system (two speed idle test)	Improper oxygen sensor operation • slow rich to lean switch time • rich biased O_2 sensor voltage
Closed loop control system incorrectly shifted lean	Plugged PCV valve or hose (two speed idle test)	Improper or inefficient operation of EGR system • restricted EGR passage • EGR valve inoperative • EGR modulator inoperative • plugged port in throttle body • faulty EGR VSV operation • leaky/misrouted EGR hoses
False input signal to ECM • incorrect indication of load, coolant temp., O2 content, or throttle position	Closed loop control system incorrectly shifted rich	Improper spark advance system operation • incorrect base timing • false signal input to ECM • improper operation of knock retard system
Exhaust leakage past exhaust valve(s) • tight valve clearances • burned valve or seat	False input signal to ECM • incorrect indication of load, coolant temp.,O_2 content,or throttle position	Carbon deposits on intake valves
Incorrect spark timing • incorrect initial timing • false input signal to ECM		
Excessive combustion blowby • worn piston rings or cylinder walls		
Insufficient cylinder compression		
Carbon deposits on intake valves		

It should be noted that due to the reduction capability of the catalytic converter, increases in CO emissions tend to reduce NOx emissions. It is not uncommon to repair a CO emissions failure and, as a result of another sub-system deficiency, have NOx increase sufficiently to fail a loaded-mode transient test. Also, when using an exhaust analyser as a diagnostic tool, it is important to remember that combustion takes place twice before reaching the tailpipe. First, primary combustion takes place in the engine. This determines the composition of catalyst feed gas, which dramatically affects catalyst efficiency. When the exhaust gases reach the catalytic converter, catalyst reduction and oxidation (secondary combustion) occur. When troubleshooting an emissions failure, the primary concern will be what comes out of the tailpipe. In other words, it doesn't matter whether the efficient burn occurred in the engine or the catalytic converter. However, when troubleshooting a driveability concern, the catalytic converter may mask important diagnostic clues, which can be gathered with the exhaust analyser.

We have seen that, although vehicle exhaust emissions are harmful to the environment, they can be reduced significantly through the re-engineering of the vehicle's engine and proper maintenance of all the vehicle's systems. Through use of an exhaust analyser, the emissions can also be used to diagnose driveability concerns the operator has with the vehicle. Through adherence to correct standards, it is possible to do as much as we can to minimise the harm our vehicles cause to the environment.

Michelle Allis is a diagnostician at WearCheck Africa

GLOSSARY

ACEA	European Automobile Manufacturers' Association (Association des Constructeurs Européens d'Automobiles
EPA	US Environmental Protection Agency
Air/Fuel (A/F) ratio	The ratio, by weight, of air to fuel entering the intake in an engine
IM240	A loaded-mode transient dynamometer test, which measures the mass of emissions collected over a 240-second, 2-mile driving cycle that corresponds with the first 240 seconds of the City Driving Test of the FTP
FTP	Federal Test Procedure
ECM	Electronic Control Module
EVAP	Evaporative Emission Control
PCV	Positive Crankcase Ventilation
VSV	Vacuum Switching Valve

BIBLIOGRAPHY

www.ucsusa.org
Union of Concerned Scientists

http://en.wikipedia.org
Wikipedia

Evaluating Vehicle Emissions Inspection & Maintenance

Board on Environment Studies Programs (2001) & Toxicology (BEST)

Fixing Emissions Test Failures
Larry Carley

Copies of previous Technical Bulletins can be accessed on WearCheck's web site: www.wearcheck.co.za

If you would prefer to receive future issues of WearCheck Monitor and Technical Bulletin via email instead of in printed form. please e-mail a request to: support@wearcheck.co.za

THE LEADER IN OIL AND FUEL ANALYSIS

KWAZULU-NATAL
9 LE MANS PLACE
WESTMEAD, PINETOWN RSA
PO BOX 15108, WESTMEAD 3608
TEL :+27(31) 700 5460
FAX :+27(31) 700 5471
support@wearcheck.co.za
www.wearcheck.co.za

WEAR CHECK AFRICA
A member of the Set Point group

GAUTENG
25 SAN CROY OFFICE PARK
DIE AGORA RD, CROYDON RSA
PO BOX 284, ISANDO 1600
TEL :+27(11) 392 6322
FAX :+27(11) 392 6340
jhbsupport@wearcheck.co.za
www.wearcheck.co.za

Felicity Howden Public Relations 5/2008