

Emission Control and Diagnosis

Motor Vehicle Emission Control Systems and Legislations



Figure 1 - Plug-in hybrid vehicle

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Table of Contents

Table of Figures	2
Introduction	3
European Emission Standards	4
The Environmental Problem with Hydrocarbons.....	5
Euro 6 Emission Standards	5
Complying for Euro 6 Emission Standards	6
Emission Control Systems	7
Catalytic Converter	7
EVAP	8
EGR	9
SAIR.....	10
PCV	11
Air/Fuel Ratio	12
Euro 7 emission standards	13
Conclusion.....	14
Bibliography.....	15

Table of Figures

Figure 1 - Plug-in hybrid vehicle.....	1
Figure 2 - OBD 2 EVAP system	6
Figure 3 - Effects of air/fuel ratio on gasoline vehicle emissions	12

Introduction

In this day and age, the most talked about factor in the motor industry is exhaust emissions and the effect it has on the environment. Engineers and developers have been working on different systems to reduce the emissions since 1992 and since then the European Union have introduced six different legislations regarding vehicle emissions. Since Euro 1 was introduced the systems fitted to modern vehicles have had a big impact on the industry as a whole, including how the vehicles are tested and what they are tested for. The newest Euro emission standard is known as the Euro 6, there hasn't been much change from Euro 5 but the biggest development since the early Euro 2/3 is the monitoring system. This will be discussed as to how the systems are monitored by new on-board diagnostic systems and what benefits they have on the emission control systems.

Taking other harmful gasses into consideration, hydrocarbons will mostly be considered in this report as it is one of the main emission pollutants that breaks down the ozone layer when entering the atmosphere (Hillier, 2014). Different emission reduction systems will be discussed along with their functionality under different engine conditions and what effect they have on the engine and the emissions. While these systems are reducing emissions, they also have drawbacks that create problems between each other for instance, if the air and fuel ratio is at 14.7:1 the hydrocarbons and carbon monoxides are reduced but the NO_x levels increase, this forces engineers into designing and developing a system that will reduce the NO_x along with the other two pollutants.

After considering what is out there in the industry with Euro 6, there are predictions about the new Euro 7 making an appearance. The effects of this will be huge for most vehicle manufacturers and they will have to consider making many changes to their powertrain systems otherwise they will not comply with the legislation. This legislation will take on new ventures such as hybrid vehicles and fully electric vehicles therefore a prediction of when and what will be done is included in this report.

European Emission Standards

While greenhouse gasses from other sectors have fallen in recent decades, those from transport have increased by 16% since 1990. Road transport remains as an important source of some of the most harmful air pollutants. These remain a concerning issue as they significantly contribute to emissions of nitrogen oxides and particulate matter in places where people live and work such as cities and towns. Therefore, vehicle emissions may not be as great as other sources but population exposure to the pollutants released by road transport can be higher than sources such as power plants or large industrial facilities because they are often situated in rural areas (EUenvironment, 2016).

In 1992 a big change was to happen in the automotive industry, this is when the Euro 1 standard introduced the catalytic converter on to petrol passenger vehicles and switched from leaded to unleaded fuel. This was implied to reduce carbon monoxide emissions from the exhaust. Since then the industry has grown in its intention to reduce emissions and is now on Euro 6 standards which has reduced some pollutants by 96% compared to the Euro 1 standards (AA, 2017). Since the Euro 6 standards were introduced emissions testing procedures and equipment have massively evolved ensuring that all vehicles comply with the current standards. The biggest change in the testing is known as RDE, this is when emissions are tested while under normal driving conditions therefore it is nearly impossible to trick the emissions test. In order to promote the harmfulness of exhaust emissions EU directives allow tax incentives for vehicles that comply with upcoming emissions standards before the standards become the law. In Germany, depending on the vehicles emission output there are many different motor-vehicle tax rates (Bosch, 2014)

The Environmental Problem with Hydrocarbons

Hydrocarbons are known to be one of the main problems when released into the atmosphere. This is because in areas with temperate climates the most widespread pollution problem is the ozone, one of the photochemical oxidants which forms from the reaction of nitrogen oxides and hydrocarbons in the presence of sun (Walsh, 1987). But as mentioned by (Bailey, 1987), in mass terms the greater proportions of hydrocarbon emissions in the UK are created by non-vehicular sources. However, according to (Walsh, 1987), the exposure of hydrocarbons into the atmosphere can result in many adverse health effects such as eye irritation, cough and chest discomfort and increases asthma attacks. Recent studies show that these health effects can show in healthy people at levels very close to the US air quality for ozone, this standard has been violated in the UK very frequently (Walsh, 1987).

Euro 6 Emission Standards

Euro 6 for light duty vehicles was brought in to reduce the amount of NO_x created by diesel engine vehicles, which was necessary to improve the air quality and comply with limit values for air pollution. In 2005 it was clear that member states would have a difficult time trying to achieve these limits by 2010 and that the adoption of Euro 6 standards would be a factor for determining this (Icct, 2016).

Petrol vehicles haven't changed much from the Euro 5 standards with the only change being that a new particle number standard for direct injection vehicles. This standard in Euro 5 only applied to diesel vehicles. Direct injection for petrol vehicles are increasingly deployed in the industry because of the continuing advancement of CO₂. This means that direct injection petrol vehicles will need an extra particulate filter for them to comply to standards due to the production of higher particle emissions compared to the older port injection method (Icct, 2016).

Complying with Euro 6 Emission Standards

For an engine that complies to Euro 2/3 emission standards there are many things that need to be addressed before it is to be compatible for Euro 5/6. The main problem with older engines is the monitoring system, this is because the functionality of the emission control systems cannot be monitored therefore the operator doesn't know if it's working or not until it gets a MOT test. This is where OBD 2 comes in, this monitoring system can detect faults within the emission control systems and alert the driver as to when the systems are failing or have failed. Emissions are only as low as possible and abiding by the law when the systems are at fully potential working order, therefore OBD 2 is required for vehicles to be as emission free as possible (Vermont, 2018).

For example, the Euro 2/3 engine is fitted with a EVAP system to ensure all hydrocarbons from the fuel tank is sent back into the combustion chamber. But, on the other hand the engine doesn't know if the EVAP is functional, this could lead to huge amounts of hydrocarbons leaking into the atmosphere. If the engine was to be brought up to Euro 5/6 standard there would need to be a monitoring system on the EVAP that would alert the operator of any leakages or malfunctions in the system.

Below is an example of how the OBD 2 EVAP system works,

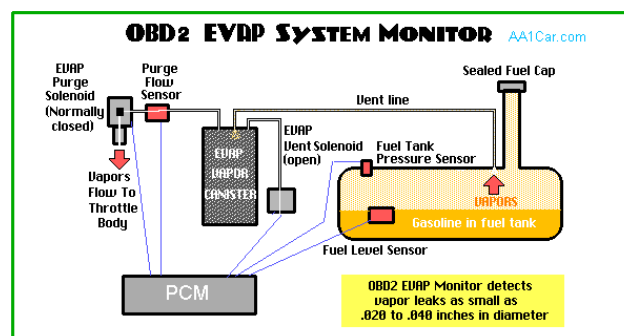


Figure 2 - OBD 2 EVAP system

According to (Miller, 2018), the newer versions of EVAP use purge sensors in the system to identify the smallest of leaks. The OBD 2 scanner will identify the leak and display a fault code for the technician (Miller, 2018).

Emission Control Systems

Catalytic Converter

Catalytic converters have been fitted onto vehicles since 1992 with the intention of converting harmful pollutants produced in the combustion process into harmless components. Petrol engine cars are fitted with a three-way catalytic converter, this will then turn hydrocarbons, carbon monoxide and nitrogen oxides into harmless components such as water vapour, carbon dioxide and nitrogen. The catalytic layer inside the housing contains metals such as palladium and rhodium, palladium will accelerate the oxidation of the hydrocarbons and carbon monoxide while the rhodium is responsible for reducing nitrogen oxide. The amount of these metals inside the housing is determined by the engine displacement and the legislation of which the vehicle is governed (Bosch, 2014).

In order to ensure the efficiency of the fuel injection and the catalyst an oxygen sensor is fitted upstream of the catalytic converter. This sensor obtains information about how much oxygen is within the flowing exhaust gasses and then, sends the information to the ECU which can control the air/fuel ratio to its desires. This will allow the correct amount of oxygen into the catalytic converter allowing it to burn off those unwanted hydrocarbons (Hillier, 2014). To ensure the catalytic converter is working efficiently, a second lambda sensor is fitted after the cat, also known as a post cat lambda. This lambda sensor will detect harmful emissions after the cat and therefore, mirror the signal of the pre-cat sensor until they both show the same signal. This indicates the failure of the catalytic converter (Denso, 2014).

Catalytic converter operating temperatures range between 300 degrees Celsius and 800 degrees Celsius, this means that when the engine is cold the catalytic converter isn't working at a 100 percent efficiency. This issue raised concerns in the industry due to the amount of hydrocarbon emissions being dramatically higher when the engine is cold, this happens because the fuel condenses onto the cold cylinder walls and leaves the combustion chamber unburnt. There are many different ways to address this issue, including idle speed adjustment and ignition timing adjustment.

Increasing the idle speed while the engine is cold will increase the exhaust gas flow which permits a greater ignition angle retardation however, reliability considerations limit the heat output which is sometimes not enough to achieve current emission limits (Bosch, 2014).

EVAP

The EVAP system is a sealed fuel system that doesn't allow vaporised fuel into the atmosphere, the system sends the vapour through a charcoal cannister and then into the induction system where it can be used in combustion. As stated by Bosch 2014, the fuel vapour escapes in larger quantities when the fuel is heated for example, when the fuel is returned back into the tank after it not being used in the combustion process (Bosch, 2014).

It consists of a cannister purge valve that is situated between the carbon cannister and the intake manifold. Due to the vacuum prevailing in the intake manifold, fresh air is drawn when the purge valve frees up, this then sucks the fuel vapour into the combustion chamber. The ECU then decides the amount of carbon volume required depending on the engine operating conditions, this has to be done regularly to ensure the cannister is able to absorb more fuel vapour (Bosch, 2014).

Due to the raising concerns of hydrocarbons entering the atmosphere and effecting the ozone layer, the EVAP system is very important in reducing the amount of those fuel vapours. The issues with the EVAP system are that there could be a leak in the system so small it will be very difficult to locate, this would allow the vapours to escape into the atmosphere at such a small scale, nobody would notice. In order to control and monitor the EVAP system, OBD2 emission regulations have certified that vehicle manufacturers have to monitor and detect leakage that exceed an area equal to a hole diameter of 0.5mm. The OBD system will use the difference in pressure between the EVAP system and atmospheric pressure, this will determine whether the leakage is within the emission regulations (Thompson, 2017).

EGR

Exhaust-gas recirculation systems were fitted on to diesel engines to reduce NO_x, this was done by sending the used exhaust gasses through a cooler and then back into the combustion chamber. NO_x reduction is done by reducing cylinder temperatures, this is achieved by reducing the velocity of combustion and because the recirculated air must be heated (Bosch, 2014).

In petrol engines the idea of having an EGR fitted is not to reduce NO_x but to keep the temperature of components down such as the turbo, if it has one, and the catalytic converter. This results in dramatically lower fuel consumption when the engine is under full load because the need to enrich the fuel mixture to reduce exhaust gas temperature is not relevant. (Bosch, 2014).

In contrast to the reduction of NO_x, according to combustion, EGR valves have disadvantages. These being that exhaust gasses are impossible to control under different engine speeds meaning that, sometimes, each cylinder receives a different amount of EGR resulting in high particulate emissions or high NO_x depending on the levels of EGR (Cambustion, 2019).

SAIR

Because the air/fuel ratio is above stoichiometric when the engine is cold on petrol engines, the secondary air injection system was devised. The system injects cold air either into the exhaust ports or into the catalytic converter, this cold air then reacts with the hydrocarbons, carbon monoxide and hydrogen. This leads to an exothermic reaction in the exhaust which can effectively reduce hydrocarbon emissions and accelerate the heat rise of the cat and, as mentioned in the catalytic converters section above, cats work at their highest efficiency when at operating temperatures (Borland, 2002).

Newer systems now have the shut-off and non-return functions combined into one, known as the secondary air-valve. But the latest is the solenoid secondary air valve that is equipped with pressure sensors for the use of OBD monitoring. To be able to comply with OBD emission regulations the monitoring of the secondary air system is necessary with OBD2 but, the EOBD will only check the electrical connection of the system and not its actions (Pierburg, 2018).

PCV

During the combustion process some of the unburnt fuel can escape past the piston rings and into the crank case, these particles are then re-used by being fed back into the induction system through the positive crank ventilation (Hillier, 2014). Without this system all of the hydrocarbons would be expelled into the atmosphere causing a lot of damage to the ozone layer, luckily this system has been fitted onto cars since the late 1960's (Baldwin, 2013).

The critical part of the PCV system is the valve, this controls the amount of vapour fed into the intake manifold. The consequences of a faulty valve could be very expensive because if the crankcase isn't ventilated properly the oil will get contaminated and not lubricate the engine as it should.

The signs of a bad PCV valve are as follows:

- Increase in internal engine pressure
- Failure of one or more oil seals or gaskets
- Engine oil leaks
- Moisture and sludge build up inside the engine
- Engine surges and black smoke could be an issue (Danny, 2017)

Also, according to Danny 2017, the valve sometimes sticks on the system which causes many issues such as high oil consumption, misfire at idle, hard engine start and a very rough idle. Therefore, if these issues occur on a car it could always be a faulty PCV valve (Danny, 2017).

Air/Fuel Ratio

Internal combustion engines completely rely on the air/fuel mixture, the mixture also has a very big impact on emission created after the combustion process. As mentioned by Bosch 2014, the theoretically complete combustion requires a ratio of 14.7:1. Thus being 14.7 of air is required to burn 1 kg of fuel. But in certain operating conditions the air/fuel requirements vary e.g. when the engine is cold (Bosch, 2014).

There are many factors to consider when taking air/fuel mixture into consideration with emissions, Robert Bosch 2014 stated that enriching the mixture may be necessary to protect components against thermal overload but in contrast it also states in the book that to get the catalytic converter working at maximum efficiency the mixture must be stoichiometric (14.7:1) (Bosch, 2014).

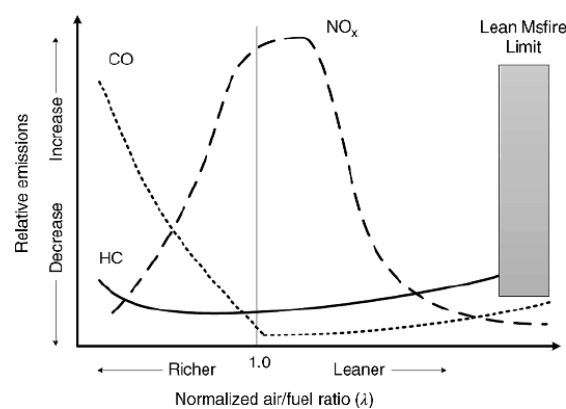


Figure 3 - Effects of air/fuel ratio on gasoline vehicle emissions

The graph above shown the consequences of different air/fuel mixtures. At the start when the mix is very rich the hydrocarbon and carbon monoxide values are high in comparison to when the mix is stoichiometric. In contrast to this the nitrogen oxide levels increase as the mixture gets leaner but after a certain point start to fall and reduce. To justify, as stated by Hillier 2014, an engine running weak mixtures with excess air will have lower combustion temperatures and lower NO_x values. Lean burn engines run in this configuration which greatly decreases NO_x emission (Hillier, 2014).

But as shown above, while the NO_x is decreasing as the mixture gets leaner, the CO and HC levels increase back to what they would be with a very rich mixture. Bosch 2014 states that when the HO and CO are higher in a leaner mix only two of the three ways of the catalytic converter function. Thus, being that the CO and HC contents can be oxidized since sufficient oxygen is still available, the reduction of NO_x cannot be carried out because the availability of reduction partners are insufficient (Bosch, 2014). This problem has forced the industry to design and fit another treatment facility to reduce the amount of NO_x.

Euro 7 emission standards

This regulation is due to be implemented in 2020 with a reduction in CO₂ by 27%. This has forced original equipment manufacturers to downsize their engines and/or turn to hybrid systems. It is predicted that the bigger manufacturer such as Toyota, Nissan and Renault will have reached this goal before this date while heavier OEM's such as BMW will have to introduce more ultra-low emission vehicles before this date. If the targets aren't met by manufacturers, they will occur a fine of 95 dollars per gram of CO₂ exceedance (Frost, 2019).

According to the Association for emissions control by catalyst, 2018, there are predictions that all vehicles fitted with internal combustion engines will remain a major development in the industry until 2030. A combination of advanced combustion engines and electric power sources in various forms of hybrid and plug in vehicles will take over and dominate beyond the next decade. Keeping the internal combustion engines will require an even cleaner combustion in the near future (AECC, 2018).

Conclusion

Thinking back to when emissions weren't talked about as much as today, the development and progress that has been made by engineers over the years is incredible. This goes to show when the (AA, 2017) mentioned that since Euro 1 emission standards were released in 1992, 96% of vehicle emissions have been reduced. Looking at the enhancements that needed to be made to an older engine to get it up to Euro 6 standards there weren't many differences to the emission control strategies only developments of what they already had. For example, the Euro 2/3 engine was fitted with a catalytic converter and a lambda, the only enhancement made to this was the second lambda fitted after the cat. This is a good example of how monitoring systems have evolved through the years and the importance of the monitoring.

After looking at the emission control systems and their monitoring techniques with OBD 2, Euro 7 is predicted to be a much more electrified and hybrid era. It is mentioned in the report by the AECC that internal combustion engines will need to be much cleaner to be competitive in the industry in the next decade. This will have a knock on effect with sources such as fuel, lubricants and technician jobs will require more training than ever. Although the internal combustion engines will remain a major element in the mix until 2030, it is predicted by Frost that bigger/heavier vehicles such as BMW will have to introduce more strategies to be able to comply with Euro 7. This gives an example of how severe this legislation is and what companies must do to comply and survive.

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