

Emissions

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Introduction

The report will investigate 6 systems which are all actively used on a modern vehicle to control emissions. The operation, emissions reduction and testing procedure will be explained and evaluated. Euro regulations will be discussed with their relevance with emission control systems. The impact of the regulations on testing and diagnosis of emission systems will be discussed.

Catalytic Converter / Temperature

A modern three-way catalytic converter converts NO_x , HC and OX into CO_2 and H_2O . A catalytic converter will store oxygen and releases when necessary. Oxygen is stored when the exhaust is lean, the oxygen is then released when the exhaust is rich. When the exhaust is rich it requires more oxygen for oxidation. (Bosch R. , 2007)

A technician uses a selection of tests to evaluate the efficiency of a catalytic converter;

Tap Test- Gently tapping the converter with a soft hammer will allow the technician to listen for rattle which shows a break-up of the material inside, if a rattle was present the converter would need replacing. (Gibson, 2019)

Back Pressure Test- Back pressure should be less than 1.5 psi and 2.5 psi at 2500 rpm. The pressure gauge can be positioned where the Lambda sensor, EGR valve or Air check valves are situated. (Gibson, 2019)

Temperature Rise- During the reduction of NO_x and the oxidation of HC and CO temperature is released. The rpm should be held at 2500 for 2 minutes. The temperature of the converters inlet and outlet pipe should be measured, a temperature difference of at least 10% should be present. If there is not temperature difference the converter is not operating correctly. (Gibson, 2019)

Exhaust Gas Analyser-

Oxygen level test- The vehicle is required to be at operating temperature, a gas analyser probe is then placed in the exhaust tail pipe. The O_2 level should be at zero percent if O_2 is greater than zero the OC level should be checked. If the OC level is greater than zero, the converter is not operating correctly. (Gibson, 2019)

Snap throttle test- The throttle should be opened fully then closed in a snap motion. The snap in throttle should force the combustion to richen and the converter should experience an influx of CO at the analyser positioned at the tail pipe. Directly after the throttle has been released the ECU will run combustion lean and O₂ levels should increase. The key reading of the test is the level of O₂ at the CO's peak. The reading of O₂ should not exceed 1.2%, if the O₂ rises above then the converter is not working. If the O₂ is 1.2% then the converter is not operating efficiently, if O₂ remains below 1.2% the converter is functioning correctly. (Gibson, 2019) (Shotton, 2016)

A modern system monitors the function of the catalytic converter using protocols. The system monitors the conversion efficiency of the three-way catalytic converter. This process measures the converters oxygen retention capacity. The system uses a three-sensor lambda control setup, this means that an additional sensor is present post catalytic converter to measure the operating efficiency of the converter. Monitoring the converter's efficiency is performed by observing lambda sensors in relation to specific variation of a set point value of the lambda closed-loop control. A value present out of the range of the set point will be registered as a fault by the ECU. (Bosch R. , 2007)

Evaporative-Emissions Control System

The system is fitted to vehicle with spark ignition, the system primarily collects fuel vapours from the fuel tank. The system is now fitted to modern vehicle to comply with governing legislation for emission limit of evaporation loss. (Bosch R. , 2007)

The system consists of a carbon canister, a vent from the fuel tank to the canister and a line and regeneration valve which is connected to the intake manifold and canister. The system operates by venting fuel vapour from the tank to the carbon canister. The activated carbon absorbs the fuel and the air can escape to atmosphere. Due to vacuum from the intake manifold, fresh air is drawn through the canister picking up fuel stored in the carbon and feeds it into the combustion process via the intake manifold. The regeneration valve controls when the intake can draw air and fuel from the canister. The operation of the valve is controlled by the ECU depending on the engines operating conditions. The system does require maintenance to ensure complete absorption of fuel in the canister, canisters may

need changing at set intervals to achieved maximum efficiency of the system. (Bosch R. , 2007)

Hydrocarbons from fuel vapour are stored in the charcoal preventing them venting to atmosphere. When in normal use the canister should not emit more than 2.0 grams of hydrocarbons when total hydrocarbon concentrate reaches 5000ppm. If the canister reaches 'breakthrough' it is emitting more than 2.0 grams of hydrocarbons for a concentration of 5000ppm. Meaning the canister has become saturated internally and cannot filter hydrocarbons from the atmosphere efficiently. The vehicle would be producing excess hydrocarbons which could be reduced using a fully functioning carbon canister. (Giorgio Martini, 2012) (Bosch R. , 2007)

Exhaust Gas Recirculation (EGR)

Exhaust gases are recirculated from the exhaust manifold to the Intake manifold via an ECU controlled valve. The exhaust gases become part of the combustion process, the benefit from this process is a reduction in combustion temperature. Exhaust gases are mixed with combustion mixture in the intake manifold, the exhaust gases produce zero combustion energy however exhaust gases add additional thermal mass. The additional thermal mass allows the combustion energy to be spread over a larger overall mass, the result of this is the combustion temperature is reduced. NO_x has an over-proportional increase as the combustion temperature rises. EGR lowers NO_x in the combustion process by controlling the mixture of exhaust gases in the combustion process, lowering the combustion temperature reduces NO_x . EGR only under certain engine operating phases to reduce NO_x , the operation is only used during cruising or similar operating phases, in contrast EGR isn't used during idle to as it would affect the smooth running of the engine. (Hillier, 2014)(Bosch R. , 2007)

Positive Crankcase Ventilation (PCV)

The system removes harmful vapor from the engine, preventing them being emitted to atmosphere. Using manifold pressure to draw vapor from the crankcase, vapor is mixed with the air and fuel mixture then burnt in the combustion chamber precisely controlled by the PCV valve. (Filter Manufacturers Council)

There are two types of system; Open system and Closed system. Open system draws air through the oil filler cap, however when large quantities of vapor is present, vapor is forced back through the cap to atmosphere releasing harmful gases. Open systems are rarely seen fitted to vehicle due to its inability to meter vapor. Closed system is used more efficiently to control emissions. The system draws air from the air filter housing, when large quantities of vapor is present it is vented back into the air filter housing where it is draw into the combustion mixture and burnt. The PCV valve in the system meters flow of vapor from the crankcase to the intake manifold. This control of vapor is essential to control flow to avoid effecting air/fuel mixture. (Filter Manufacturers Council)

The PCV valve is controlled by manifold vacuum, at low engine speed (high manifold pressure) the valve is closed or open very slightly. As pressure in the manifold decreases the valve opens wider allowing more vapor through to the intake manifold. The valve only opens a maximum of halfway when allowing maximum vapor to flow, this is to allow for the possibility of a back-fire. If a back fire occurs the valve is closed by sealing against the opposite end of the internal of the valve casing. Preventing a back-fire passing into the crankcase is essential to avoid igniting combustible vapor. (Filter Manufacturers Council)

A failed PCV system causes many issues to the engine. If the crankcase is not vented correctly then the engine will become contaminated leading to sludge accumulations being formed. Corrosion will begin to occur inside the engine due to water and acids being trapped. Depending on how the valve has failed it will affect the idle and running of the engine if proper metering is not happening. (Filter Manufacturers Council)

The PCV system can be tested by monitoring engine idle speed. The idle speed should be monitored against manufactures specification, if a great difference appears the system should be checked for faults. (Bosch, 2006)

Secondary Air Injection

An engines operation can be largely impacted by the use of secondary air injection (SAI), this can be seen when an engine is tested with SAI operating and when SAI is not operating during the same engine operation period. When SAI is active Hydrocarbons (HC) emissions are 60% lower than when SAI isn't active, 45s after engine start up, this is due to the air being injected which oxidises the HC as there is normally no oxygen present during start up.

SAI being active allows a catalytic converter heating strategy which achieves an 80°C higher converter inflow temperature which is achieved 20s after first engine operation. (Dr Holger Paffrath, 2010)

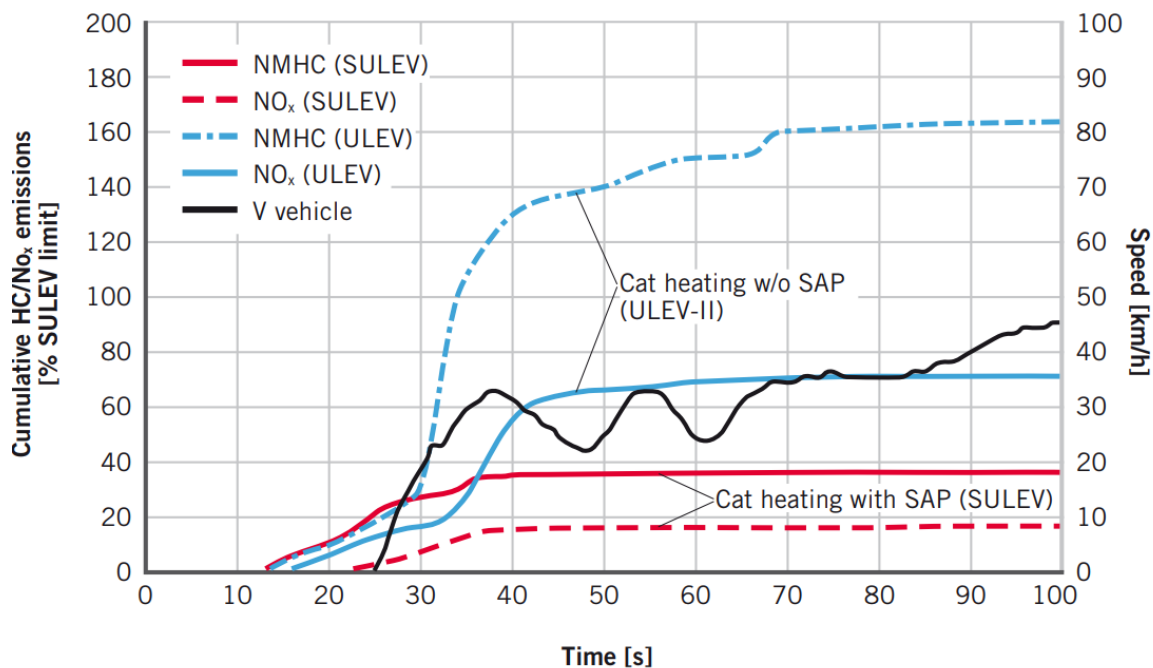


Figure 1- Cumulative emissions from exhaust analysis test (Dr Holger Paffrath, 2010)

Figure 1 shows how engine start produces different amount of emission with SAI active and without SAI active. The difference is small until 30s after engine start up, at which point the emissions of the engine without SAI increase heavily, whereas the engine with SAI active has dramatically lower emissions output which remains at a constant. This is due to the early heating of the catalytic converter caused by the use of SAI. Rapid heating of the Catalytic converter allows an earlier period in which the catalytic converter can control emissions. A reduction of NO_x is seen in figure 1 when SAI is active. This reduction is not due to the air being injected but a knock-on effect of rapid heating of the catalytic converter. (Dr Holger Paffrath, 2010)

SAI varies its mode of operation depending whether the engine operating is hot or cold. When the engine is cold a rich mixture is used to allow a smooth, stable and miss-fire free operation at low idling speed. A rich mixture results in incomplete combustion producing carbon monoxide (CO) and Hydrocarbons (HC). SAI oxidises these emissions in the exhaust manifold, the rapid heating of the catalytic converter allows for further reductions in

emissions in initial cold running of the engine. During hot operation of the engine a lean air/fuel mixture tends to be used, SAI is not normally active however NO_x is produced from lean mixture. NO_x is reduced quicker due to the rapid heating of the catalytic converter during cold running when SAI was active. During hot operation the engine may use a rich mixture during heavy acceleration, SAI can be activated during this period to provide extra oxygen to help oxidise HC and CO. (Dr Holger Paffrath, 2010)

SAI heavily reduces CO, HC and NO_x as a result of its operation. SAI during cold start reduces 60% of HC emissions compared to an engine without SAI. HC and CO are reduced heavily by oxidising the emissions in the exhaust manifold pre catalytic converter when the Catalytic converter is not at operating temperature. These emissions without SAI would be released into atmosphere until the catalytic converter reached operating temperature. NO_x is produced after SAI has been deactivated however the rapid heating of the catalytic converter means engines SAI has seen a reduction in NO_x as the catalytic converter is operating earlier. (Dr Holger Paffrath, 2010)

SAI can allow for alternate engine component layouts including the catalytic converter, for example the catalytic converter can be position further away from the exhaust manifold. The catalytic converter being position further away from the exhaust manifold is possible through rapid heating which is a result of SAI being active. The catalytic converter being positioned further down the exhaust system means catalytic cooling through mixture enrichment is not necessary, this means HC and CO which is produced during mixture enrichment are not produced. Emission advantages from SAI are free from any negative effects on the engine's operation and production of emissions. (Dr Holger Paffrath, 2010)

Air / Fuel Ration

The air/fuel (A/F) ratio has an pivotal impact on the exhaust gas system. A three-stage catalytic converter needs a stoichiometric ratio to operate at maximum efficiency. Carbon monoxide (CO) is produced as a result of incomplete combustion. When the engine is operating in an un-homogeneous a/f ratio. Fuel droplets fail to vaporise due to a rich mixture of the engine's combustion. Hydrocarbons (HC) are caused by incomplete burn of the a/f mixture when there is an oxygen decency. This process creates new HC which may not have been present in the original fuel, this is a result of the separation of extended

molecular chains. Nitrogen oxide (NO_x) are produced during all combustion processes where air is present, this is caused by a secondary reaction of nitrogen from the air and oxygen present in the combustion process. (Bosch R. , 2006)

To achieve maximum emissions reduction during engine combustion the engine must operate using a stoichiometric a/f mixture this is also referred as Lambda ($\lambda=1$). A stoichiometric ratio should be used in conjunction with a three-way catalytic converter to provide maximum efficiency in emission reduction. During a $\lambda=1$ operating phase CO, HC and NO_x are produced but reduced due in comparison to other operating conditions, the efficiency of the combustion burn means incomplete combustion is minimal reducing CO and HC. (Bosch R. , 2006)

An engine operating with direct-injection operates in stratified-charge and homogeneous modes depending on the engine's demands. During homogeneous mode the engine injects fuel during the intake stroke. The engine runs in homogeneous when it requires high torque at high engine speed. In this mode the a/f ratio is operating in a factor equal to $\lambda=1$. The produces the same emissions outputs as seen with stoichiometric a/f ration. (Bosch R. , 2006)

During Stratified-charge operation the fuel is injected during the combustion stroke, the mixture cloud formed at the centre of the combustion chamber. The air in the combustion chamber should be the same of that found in $\lambda=1$. However, an extremely lean mixture is created by the reduction of fuel present, made possible by the precise timing of injection. This results in a more complete combustion burn and an overall a/f ration of $\lambda>1$ for the entire combustion of the cylinder. A lean mixture produces NO_x which is reduced by the catalytic converter before it reaches atmosphere, furthermore during lean burn CO and HC are not produced reducing the overall emissions produced by the engine. (Bosch R. , 2006)

HC can be produced during stratified-charge, HC are produced during the extremities of the combustion chamber. HC are produced when fuel is deposited as liquid causing a film in the combustion chamber, this leads to incomplete combustion of fuel. When the engine is operating in a lean a/f ratio oxygen is not present in the exhaust system, this means the reduction of HC by the catalytic converter before they reach atmosphere is not optimised. Systems have been added to engines on modern systems to help further with emissions, in

this case secondary air injection would assist with the reduction HC during lean burn by injection oxygen to help oxidise HC. (Bosch R. , 2006)

A test can be conducted to evaluate the ECU's control of the a/f ratio. Using an oscilloscope, the voltage from the lambda can be monitored by its output. The engine must be ran at fast idle for a few minuets to make sure the sensor is warm enough to operate correctly. The sensors voltage should be checked at 2000rpm where a fluctuation between 0.2v and 1v should be present with an overall average of 5v. If the voltage average is higher than 0.5v the engine's a/f ration is rich, if the voltage average is lower than 0.5v then the a/f ratio is lean. (Gibson, Oxygen Sensor Update, 2019)

Euro 6

Euro emission regulations for petrol passenger vehicles focus on reducing CO, HC and NO_x, Euro regulation set a limit of gases which a manufactures vehicle can produce when it goes into production. Euro 1 was released in 1992, now Euro 6 current regulations which came into place in 2014 must be followed by car manufactures. These emission regulations can be seen below in figure 2. (Hillier, 2014)

<i>Emission tier</i>	<i>Date</i>	<i>CO (g/kg)</i>	<i>HC (g/kg)</i>	<i>NO_x (g/km)</i>	<i>NO_x + HC (g/kg)</i>
<i>Euro 1</i>	<i>July 1992</i>	<i>2.72</i>	<i>-</i>	<i>-</i>	<i>0.097</i>
<i>Euro 2</i>	<i>January 1996</i>	<i>2.2</i>	<i>-</i>	<i>-</i>	<i>0.5</i>
<i>Euro 3</i>	<i>January 2000</i>	<i>2.3</i>	<i>0.2</i>	<i>0.15</i>	<i>-</i>
<i>Euro 4</i>	<i>January 2005</i>	<i>1.0</i>	<i>0.10</i>	<i>0.08</i>	<i>-</i>
<i>Euro 5</i>	<i>September 2009</i>	<i>1.00</i>	<i>0.100</i>	<i>0.060</i>	<i>-</i>
<i>Euro 6</i>	<i>September 2014</i>	<i>1.00</i>	<i>0.100</i>	<i>0.060</i>	<i>-</i>

Figure 2- Euro emission regulations for petrol passenger vehicles (Hillier, 2014)

The Ford Zetec EEC IV was in production whilst Euro 3 regulations were being enforced, these regulations stipulated that a maximum 2.3 g/kg of CO and 0.2 g/kg of HC can be produced. Euro 6 regulations have restricted the allowance, a maximum 1.0 g/kg of CO and 0.100 g/kg can be produced and emitted into atmosphere. (Hillier, 2014)

The Ford engine could be brought in line with Euro 6's regulations of CO and HC with the fitment of additional emission control systems. Secondary Air Injection (SAI) would allow the engine to control the production of CO and HC. The Ford engine is fitted with a catalytic converter as these have been compulsory on all production vehicles since 1993, however for

improved control to work in hand with SAI a three-way catalytic converter would have to be fitted to the system.

SAI would operate during cold start, reducing CO and HC which are produced and released to atmosphere as the Catalytic Converter is not at operating temperature during cold start phase. With 90% of pollutants emitted during the first minute of a drive cycle (Empa, 2017), SAI has a major impact on the overall emissions produced by the vehicle. SAI is monitored to comply with Euro 6's monitoring of systems regulations, SAI system uses an air flow meter to monitor the amount and when air is injected. The ECU uses this air flow meter and the lambda sensor to establish whether the system is functioning correctly. (Dr Holger Paffrath, 2010)

Overall SAI would allow the Ford engine to comply with Euro 6, HC has been shown in figure 1 to reduce by 60% in the first minute of cold start when tested against a engine without SAI. CO and HC are reduced when oxygen is present in the exhaust manifold injected by the SAI system during cold start. The oxygen allows for oxidation of the gases to take place, this only takes place when SAI is active. Systems without SAI release these emissions to atmosphere during cold start, this is due to the catalytic converter not operating at working temperature and unable to efficiently oxidise CO and HC. NO_x is not produced during cold start when SAI is active, however engines equipped with SAI have a reduction in NO_x in comparison to vehicles not fitted with SAI. NO_x is reduced by a knock-on effect of SAI though rapid heating of the catalytic converter; rapid heating is caused by heat generation from the exothermal reaction in the exhaust manifold. Rapid heating means the catalytic converter reaches operating temperature quicker, this process allows a reduction of NO_x pre catalytic converter earlier in the engines operating period. (Dr Holger Paffrath, 2010)

Conclusion

Euro regulations have meant systems have greatly advanced to reduce harmful pollutants which without these systems a vehicle's emissions would be emitted to atmosphere. Modern regulations of self-test and diagnosis of systems within the vehicles ECU, allows for emission limits to be kept through the life of the vehicle minimising the possibility of pollutants be emitted due to a system not operating correctly. Euro 7 is due to be introduced in 2020/21 this will be another advancement in emission control as regulations

become stricter (European Emission Regulations - Will Stringent Emission Regulations Choke Automotive Industry Or Will OEMs Find Their Way Out?, 2016).

The report has investigated how emission control systems have advanced and developed, the positive benefits to a vehicles production of emissions. The advancement of emission control systems has been followed by changes and development of test equipment, which a technician is able to utilise to monitor the operation and efficiency of the emission control systems.

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