Combustion and EGR Part 2

In this second part of the series, the Institute of the Motor Industry (IMI) continues looking at the combustion process, stoichiometry and emissions in petrol and diesel engines, concentrating on diesel exhaust gas recirculation (EGR), and the differences between them.

The first thing that should be known is that petrol and diesel combustion ingredients are identical: Air (78% nitrogen, 21% oxygen and 1% other gasses) and fuel, a refined blend of 16% hydrogen and 85% carbon. It is the way they are mixed and the different characteristics of the larger diesel fuel molecules that make them different.

Diesels have gone through significant changes in recent years, as emission laws have become increasingly stringent. The common rail system is now the industry standard, due to its higher efficiency and greater emission control. The common rail system injects fuel in stages at very high pressures (approx 1500 Bar) into the cylinder.

The combustion process is broken down into various stages (up to 7) but consists of 2 main stages:

Pilot injection: pilot injection reduces knock caused by the delay between the injection and the ignition of the fuel. It does this by injecting a small amount of fuel into the compressed air before top dead centre (TDC). This gives time for this small amount of fuel to ignite. Knock is traditionally caused by the delay as fuel heats up to its ignition point. The longer the delay, the more fuel that will be in the cylinder, causing a large uncontrolled pressure rise around TDC which is what can be heard as knock.

Main injection: As the piston nears TDC, and while the pilot injection is still burning, the ECU injects fuel into the cylinder. This provides a rapid, smooth rise in pressure and allows torque control via the amount of fuel injected. This method of injection maximises efficiency by burning all the fuel evenly, thus minimising undesirable emissions.

The emissions from diesel combustion are almost identical to those of a petrol engine:

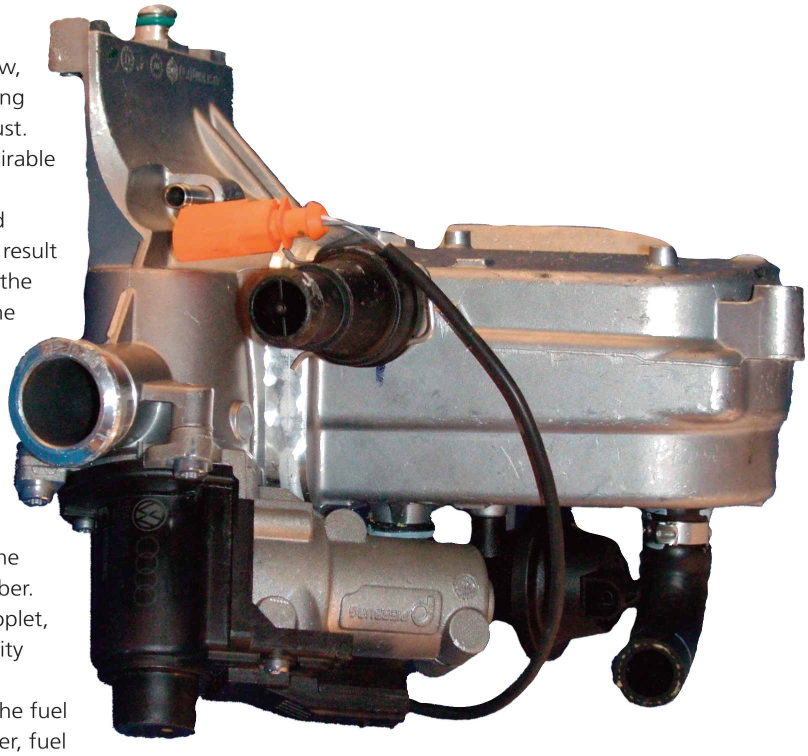
Carbon monoxide (CO): a by-product of incomplete mixing of the carbon and oxygen. With direct injection, the epicentre of combustion occurs at the centre point of the injector. The flame spreads from the centre outwards, resulting in poor mixing at the furthermost points.

Carbon dioxide (C02): the normal result of combustion resulting from carbon mixing with oxygen correctly.

Hydrocarbons: raw, un-burnt fuel exiting through the exhaust. They are an undesirable emission and are completely wasted energy. This is the result of poor mixing of the air and fuel and the time it takes for the flame to spread. Unburnt fuel is usually the result of poor atomisation and penetration into the combustion chamber. The bigger the droplet, the lower its velocity and liklihood of clumping. When the fuel is clumped together, fuel on the outside of the clump combusts and forms a barrier between the fuel in the centre of the clump and the available oxygen. Poor air movement and bad injectors are the most common causes of incomplete combustion

Particulate matter (soot): created when carbon is starved of oxygen. This causes the carbon to become baked during the large temperature increase and it is then exhausted into the atmosphere.

Oxides of nitrogen (NOx) Unlike a petrol engine, intake air is not restricted on a diesel engine. They take in a cylinder full or more with every stroke.



An EGR Intercooler from a late model 1.6l Diesel VAG

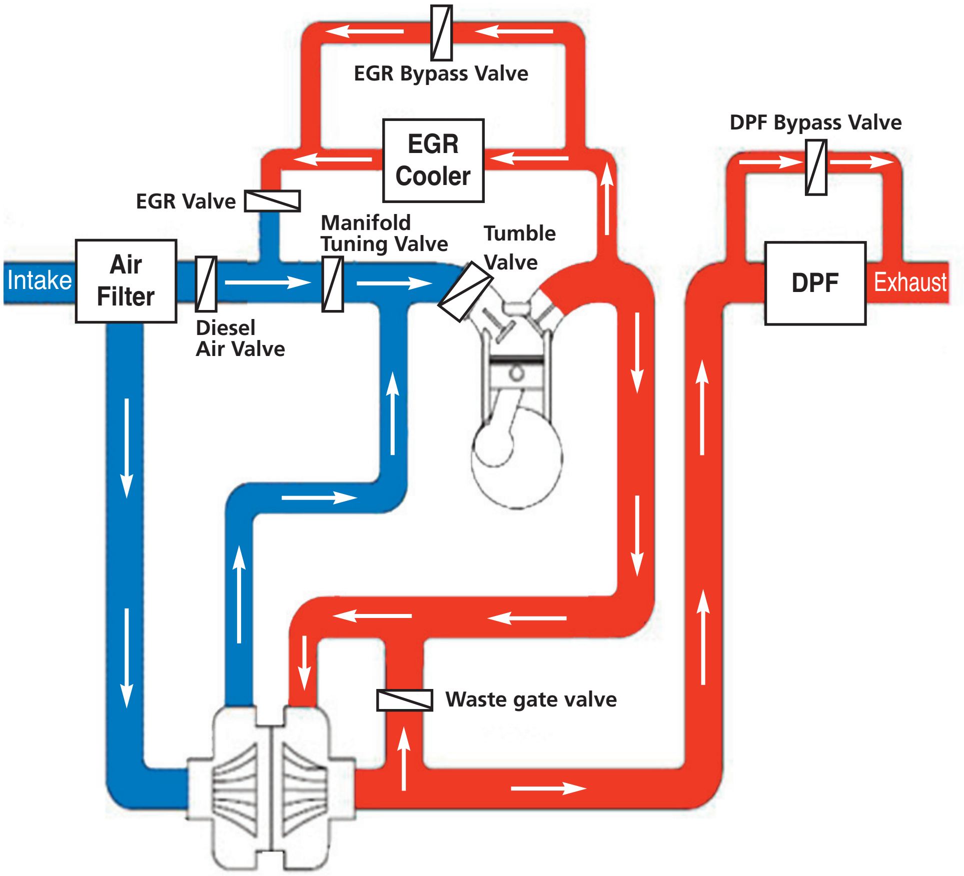
New technology brings new types of failure

As you might imagine, every new technology or design brings a new type of possible failure. In the case of EGR intercoolers, there are ways that they can fail and cause you to suspect something else entirely. What is required to avoid this costly and time-consuming trap, is knowledge of what the new technology does, what it doesn't do and how to test it for proper operation.

An EGR intercooler brings engine coolant and exhaust gasses into close proximity, and provides another path for coolant to leak into the exhaust. If an EGR intercooler has an internal leak, you might not be able to see it directly.

If you have a car that is losing coolant, white steam is coming out of the exhaust and exhaust gasses can be detected at the radiator cap, you might suspect a bad head gasket or a cracked head. With an EGR intercooler present, you have to consider that the intercooler may be leaking before tearing the head off. Bypass or stop the coolant flow through the intercooler and see if the leak is still present. A simple step that will save you time, money and your customer's faith.

The engine torque is controlled by the amount of fuel injected. The air/fuel ratio varies from 17:1 to 29:1 under load, and 50:1 to 145:1 at idle or no load. This means that a diesel engine only ever runs close to stoichiometric proportions at full throttle and load, unless there is a fault. Unfortunately, very high localised temperatures within the combustion chamber lead to the production of NOx. There are a number of strategies to control NOx emissions and the most common is exhaust gas recirculation (EGR). Exhaust gas is a mixture of CO2, H2O (water vapour), nitrogen, and oxygen. Two effects of EGR are: CO2 and H2O thin out the oxygen in the inlet air and slow the rate of combustion. H2O, water vapour, has a high specific heat capacity (SHC) and causes a reduction in peak combustion temperatures, and therefore NOx production. SHC describes the amount of heat energy it takes to raise the temperature of a substance. Air has an SHC of around 1kJ/kg/°C whereas steam has an SHC of 2.25kJ/kg /°C



An example of a more complex diesel EGR design with a turbocharger

Differences between petrol and diesel

Diesel is distinctly different to petrol in relation to manifold pressure. Diesel engines use throttle pedal angle as a demand for increasing or reducing fuel supply. This means that the pressure drop associated with conventional throttles is not used for restricting air flow. Instead, the engine ECU controls the amount of throttle opening for alternative gains. These benefits come in the form of reducing noise during idling and deceleration, as well as noise and vibration that are generated when the engine is stopped. During EGR operation, the throttle valve moves towards the closed position to increase manifold vacuum. This means that a greater amount of EGR can be introduced into the inlet air.

EGR operation

While the modern diesel has been refined to be very efficient, it has still not completely eliminated emissions of NOx. The strategies used to control NOx emissions have become very advanced and complex, due to the variety of operating strategies used.

Just like in petrol engines, the same goal exists of cooling the exhaust gasses once they have left the cylinder. The recirculated exhaust gas will then absorb some of the heat produced during combustion by increasing the heat capacity of the mixture in the cylinder.

EGR can be controlled by various methods such as a control solenoid or an electro valve operation. The solenoid can be powered by the ECU to open and close, dependent on engine load. The electro valve operation uses the brake servo pump to actuate the pressure differential at the EGR diaphragm.

While petrol engines use EGR at light load and high engine speed, diesel engines use their EGR systems throughout their operating range, and can provide as much as 60% of the total intake air at idle. This aids warm up of a cold engine and also reduces idling noise significantly. Because of the constant use and harsh conditions, EGR coolers are commonly used. This involves exhaust gasses travelling through a heat exchanger, depending on operating conditions, such as during warm up or full throttle. This ensures sufficient cooling of the recirculated gas before entry back into the cylinder. Some coolers feature an oxidation catalyst to minimise clogging in the cooling fins caused by HCs and particulate matter.

EGR feedback

Due to the amount of EGR that is introduced into a diesel engine, the engine management system requires some form of feedback to monitor operation. EGR feedback can be measured in various ways. Measurements of manifold pressure and air flow on some systems is enough to calculate EGR. Some systems use actual EGR valve opening values, measured via the actuator solenoid, to provide the engine management ECU with a real time value.

Wide or broad band oxygen sensors are becoming more popular. These sensors are the most accurate way to monitor oxygen content in the exhaust gas. This data can then be used in a similar way to that of a petrol engine management system, as a closed loop control to monitor and control EGR actuation against the pre programmed map value in the ECU. If the sensor detects a lean situation, EGR is increased causing the mixture to enrich. When the sensor detects a rich mixture, EGR is reduced causing a leaner mixture.

The values detected are also used in conjunction with corrective injection duration. This has a significant difference to the overall drivability and the emission output of the modern diesel vehicle. In addition to EGR control, other factors, such as particulate filters and NOx reducing catalysts, are used to further reduce emissions.