ThermoGuard Instruments

Tech Talk

Issue No.1

Why Diesels are Different

(and some fundamental differences between petrol and diesel engines.)

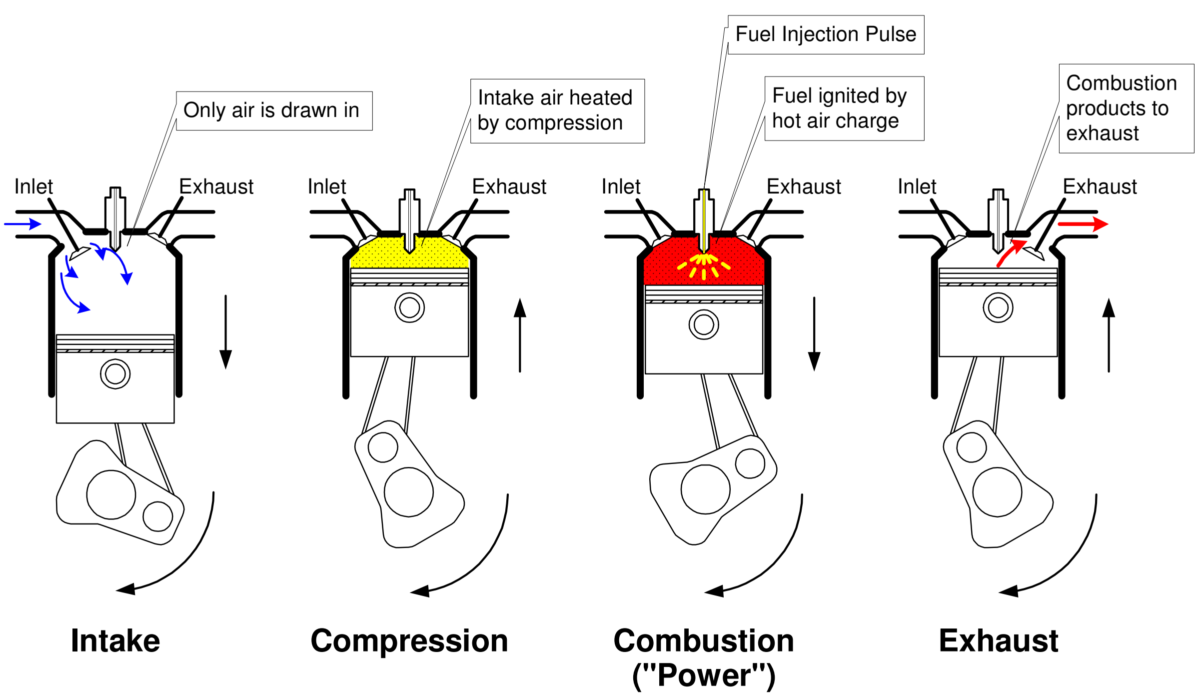
This is the first in what is intended to be a series of short articles discussing various diesel engine technical issues. This first article discusses the basic operation of typical automotive diesel engine and, especially, the fundamental differences between diesel and petrol (gasoline) engines.

[*This information is presented for the interest of the reader only. The author accepts no responsibility for any adverse outcomes which may result from the reader using all or any of the information presented in practical applications.*]

Starting point

This article assumes a basic understanding of reciprocating internal combustion engines which operate on the four-stroke cycle (see diagram below). If this sentence is gobble-de-gook to you, may I suggest you find a book or article that explains the fundamentals of internal combustion engines before returning to read this article?

4-stroke Compression-ignition (Diesel) Engine Cycle



The primary intention is to make readers, who may well be experienced with the basics of petrol engines, aware of some of the important differences in the operation of diesel engines.

Only four-stroke (or four-cycle) automotive engines will be discussed here, as they are almost universally used in passenger vehicle and light truck (including 4WD) applications. Two-stroke (two-cycle) engines are commonly used in garden equipment (lawn mowers, chainsaws, etc.) and small motorcycles. Also, heavy truck, large industrial and marine diesel engines are sometimes two-stroke engines. However, they will not be discussed further in this article.

Terminology

Engines in which combustion is initiated by an electric spark plug in the cylinder head are known, not unreasonably, as "spark-ignition" or SI engines. These typically burn light hydrocarbon fuels characterised by their Octane Rating. These fuels may be called, depending on your location, 'petrol', 'gasoline', 'benzin', etc. Spark-ignition engines can also burn, and are commonly modified to burn, Liquefied Petroleum Gas (LPG), which is typically a blend of Propane and Butane.

Engines in which combustion is initiated by the heat attained by the high compression of the air charge in the cylinder are known (again quite reasonably) as "compression ignition" or CI engines. These typically burn heavier hydrocarbon fuels characterised by their Cetane Rating. These fuels may be called, depending on your location, 'diesel', 'distillate', 'DERV', 'gasoil', etc.

To avoid possible confusion, we will not refer to the engine types by the names of their fuel (petrol/gasoline or diesel/gasoil); rather we will use the terms spark-ignition (SI) and compression-ignition (CI).

Another term we need to look at is "stoichiometric combustion". This term describes the situation where air and fuel are combusted in just the 'right' proportions. That is, all of the fuel is fully burnt and all the oxygen in the air is consumed in the process. At the end of the combustion process there is no unburnt fuel and no oxygen remaining in the products of combustion.

While stoichiometric combustion in an engine would theoretically give the best efficiency, for various practical reasons, exactly stoichiometric combustion is seldom desirable in 'real world' engines.

Similarities

Both SI and CI engines ingest air from the atmosphere, add (by various means) an appropriate quantity of the relevant fuel, combust the air and fuel, and expel the products of combustion to the atmosphere. In the process, <u>some</u> of the energy released by combustion is converted to torque to propel the vehicle. Unfortunately, however, the majority of this energy is lost as heat, either absorbed by the metal of the engine (and subsequently dispersed by the engine's cooling system) or carried out with the exhaust gas. All reciprocating internal combustion engines are quite thermally inefficient (much less than 50% efficiency). However, modern technology is continually improving efficiency in new engine designs.

Differences

Ignition

We have already mentioned the different methods used to initiate combustion in SI and CI engines. This is a fundamental difference: CI engines depend completely on compressing air enough to achieve a temperature capable of igniting the fuel, as it is injected. SI engines, on the contrary, must avoid achieving compression temperatures which might cause combustion to begin before the spark plug fires. If the air/fuel mixture in a SI engine self-ignites (pre-ignition or 'pinging')[1] before the spark plug fires, severe damage can result to the engine.

[1] Pre-ignition and/or 'pinging' is a complex subject. It can also occur after normal spark-plug firing due to issues relating to the Octane rating of the fuel, the compression ratio or deposits in the combustion chamber. This subject will not be further discussed here.

Fuel delivery

SI engines traditionally used a device called a carburettor to add fuel to the engine's incoming air charge. Carburettors use the venturi effect to draw fuel into the air stream through a fine orifice called a 'jet'. The fuel flow from the jet is (hopefully) a fine spray of fuel droplets which are largely vaporised by the time the 'mixture' reaches the engine cylinders.

More modern SI engines use fuel injection, to pump a spray of finely-atomised fuel into the air stream entering the engine. Most modern engines will have one fuel injector in each cylinder's inlet tract. The injectors are almost universally electronically-controlled by an Engine Management System (EMS). Electronic fuel injection and associated engine management techniques are largely responsible for the great improvements made in specific output (kW per litre) and economy in the last decade or so. The latest development in SI engines is Direct Injection, in which the fuel charge is injected directly into the combustion chamber, rather than into the inlet tract.

CI engines always have their fuel injected into each cylinder's combustion chamber (even though it is sometimes referred to as a "pre-combustion chamber", in some designs). This is so because the beginning of combustion in a CI engine is totally controlled by the beginning of injection of fuel into the cylinder full of very hot air.

Traditionally, fuel injection in CI engines is performed by a mechanical high-pressure pump (injection pump) which pumps fuel charges to individual cylinder injectors. Modern designs include either electronically-controlled functions to enhance the performance of mechanical injection pumps or, increasingly, use fully electronically-controlled cylinder injectors, which are fed from a common high-pressure fuel manifold or 'rail' (Common Rail Injection).

Mixtures, Air/Fuel Ratios, 'Rich' and 'Lean'

This topic is one in which the fundamental differences between SI and CI engines manifest themselves.

SI Engines

All SI engines have air/fuel mixtures existing in the cylinder before combustion is initiated by the spark plug. These mixtures may exist continuously in the inlet manifold (in the case of carburettor or 'throttle body injection' systems). Or, they may exist only after each cylinder begins its induction stroke (in the case of 'traditional' individual inlet tract injection). Or they may exist for only a short period in each cylinder before the spark plug fires (in the case of Direct Injection).

If such an air/fuel mixture exists, it follows that the quantities of air and fuel must exist in proportions which can be expressed as a ratio – the air/fuel ratio. The stoichiometric ratio for air and petrol (gasoline) is roughly 15:1. That is, for complete combustion without excess air, we need 15 times the quantity of air as the quantity of fuel. If there is less air in relation to fuel (say 13:1 ratio), it is called a 'rich' mixture. If there is more air in relation to fuel (say 17:1 ratio), it is called a 'lean' mixture. SI engines will only operate over a fairly narrow range of air/fuel ratios – if it is hugely rich or lean, it won't ignite at all. Therefore, even at idle, a close to stoichiometric ratio must be maintained and, to keep the engine speed at 'idle' rpm, the mass of both air and fuel ingested is severely restricted by the throttle. In fact, the main throttle valve is just about fully closed and a relatively tiny bypass passage allows a small quantity of air (or air/fuel mixture, the case of carburetted engines) into the engine.

In SI engines, close to stoichiometric combustion is desirable under steady cruising conditions, to give optimum economy, and most engine management systems constantly sample the exhaust gas stream to keep the quantity of excess air (oxygen) at a very low but measurable level. However, during acceleration, better performance is obtained with slightly rich mixtures and the EMS will 'enrich' the mixture under these conditions. What must be avoided at all costs, however, is excessively lean mixtures, especially under heavy load conditions. The lean mixtures cause far higher peak combustion temperatures and lead to rapid erosion of the exhaust valve and valve seat and, in extreme conditions, can cause a hole to be burnt in the piston crown.

CI Engines

As combustion begins only when fuel injection begins in a CI engine, the notion of an air/fuel *mixture* ceases to have much meaning. A 'mixture', if it exists at all, exists only for the instant between the beginning of injection and the beginning of combustion – a matter of a few milliseconds at most. Similarly, air/fuel ratios have little meaning in CI engines. The air/fuel ratio does not exist as a semi-continuous parameter which changes only over a narrow range, as is the case in SI engines.

Certainly there is an air/fuel ratio for each power stroke of each cylinder but it really only has some quantifiable value at the end of the fuel injection pulse, when all the fuel that is going to be injected in that power stroke has been delivered. And it is always (or should be) a very 'lean' ratio. CI engines operate most of the time with a large proportion of excess air.

Why is this so? Well, remember that CI engines only work if the cylinder contains a charge of air which has been compressed enough to heat it above the ignition temperature of the fuel. To ensure this, generally the inlet of air into a CI engine is un-throttled and roughly the same mass of air is ingested by each cylinder whether the engine is idling or at full load. [OK, I admit this is not strictly true in the case of forced-induction (turbo-charged or super-charged) CI engines, but that's a matter for more detailed discussion at a future date.]

What changes over a wide range is the quantity of fuel injected into each cylinder. At idle, only a tiny squirt of fuel is required to keep the engine 'ticking over'. So, the air/fuel ratio is extremely 'lean' compared to stoichiometric – perhaps more than 100:1 At steady low speed cruising, say between 60 to 80 km/h, it may be of the order of 40 or 50:1. At full load and full throttle, it may be approaching 20:1

So, why don't these very 'lean' ratios cause damage to CI engines, such as may occur in SI engines under 'lean' conditions? Well, consider this: extreme combustion temperatures occur when the air/fuel ratio in a cylinder is *just* on the lean side of stoichiometric. Once considerable excess air is available in the cylinder, this mass of un-reacted air is able to absorb much of the heat generated by combustion and the overall cylinder gas temperature is kept to relatively low levels. This energy is not wasted; the excess air expands as it absorbs heat and it all helps to push on the pistons.

Over-fuelling

If the air/fuel ratio in a CI engine's cylinder approaches too closely to stoichiometric, the percentage of excess air is small and combustion temperatures can reach excessively high levels. This is a condition known as "over-fuelling", even though the overall ratio is still a little on the 'lean' side of stoichiometric.

Generally, the engine will be producing visible black smoke under these conditions. The smoke is tiny particles of carbon (soot) which have been generated by the breakdown of the hydrocarbon fuel, but not completely reacted with oxygen, to form carbon dioxide. Even in this situation, there will still be some excess air in the cylinder but it has just not been possible for all the carbon and oxygen to 'find' each other and combine. These conditions result in the peak combustion chamber temperatures and can in the extreme, cause burning of piston crowns and exhaust valves, as in SI engines.

Over-fuelling is most easily detected by measuring the temperature of the exhaust gas as it leaves the engine – measuring Exhaust Gas Temperature or EGT. The instrument used to measure EGT is known as a Pyrometer or, not unreasonably, an EGT gauge.

Causes of excessive EGT

In a well-maintained standard engine, with a correctly calibrated and timed fuel injection pump, the quantity of fuel injected **should** rarely, if ever, exceed that which can be efficiently combusted with the mass of air available. CI engines which have been 'tuned' for improved performance <u>are</u> likely to generate higher than normal EGT under heavy load conditions, even if the fuelling has been adjusted on a dynamometer.

But even with the best efforts of the factory or tuning specialists, excessive EGT can still occur due to a number of not uncommon factors:

Not enough air

The most likely cause is a restricted air supply to the cylinders. As well as the obvious possibility of a clogged air filter element, other possible causes that have been known to affect various engines include:

- Collapsing air inlet hose/duct,

and on turbo-charged engines:

- De-laminated or partially blocked hoses at the turbo outlet and/or intercooler
- Fouled/restrictive intercooler (either internally or externally).
- Air leaks, faulty waste gate or a partially blocked exhaust on turbo-charged engines, leading to low boost pressure. [*Yes, lower than normal boost pressure can cause high EGT*!]

Too much fuel

Excessive fuel delivery will also cause high EGT. This could be a result of a failure within the injection pump itself, but is more likely to be a result of over-zealous 'tuning' of the pump.

These days, many specialists offer tuning services to turbo-diesel owners to improve towing and overtaking performance. These modifications usually provide very satisfactory results but invariably lead to the engine operating closer to the limits at full load.

If 'overdone' or if any of the other factors mentioned previously come into play, excessive EGT can quickly result - *and the damage may be done before any indication of a problem is provided (if at all) by the vehicle's standard coolant temperature gauge*.

Acceptable Exhaust Gas Temperature

By far the best place to measure EGT is in the exhaust manifold. If the engine is turbo-charged, this means upstream of the turbo-charger (that is between the exhaust ports and the turbo exhaust gas inlet). When measured here, it is generally accepted that sustained temperatures in excess of 720 °C (~1330 °F) will result in progressive and irreversible damage to components.

On some turbo-charged vehicles it is difficult to install the sensor upstream of the turbo-charger, so a downstream position is used, usually in the exhaust pipe just below the turbo exhaust outlet flange. There is, however, a large temperature drop across the turbo-charger at full load, which may exceed 200 °C. Therefore, for downstream installations, a maximum temperature of 520 °C is recommended.

Controlling over-fuelling and excessive EGT

If excessive EGT is being recorded, how can it be reduced to a 'safe' level? In the very short term, just back off! Very high EGT will only occur if the engine is operating at high load. Operating at less than full throttle should drop EGT almost immediately. If the high EGT occurs while climbing a steep gradient, changing to a lower gear and driving at a lower speed will normally do the trick.

Of course, should the excessive EGT occur under conditions which are normally not a problem for a particular vehicle/engine, then it may be due to other abnormal causes, as mentioned previously.

The end bit

Other articles in this series will look at forced-induction (turbo-chargers and super-chargers) as applied to CI engines, charge cooling (intercoolers), traditional and modern methods of CI fuel injection control.

Feedback

I hope this article has been found interesting. I'd welcome feedback on the topics raised. If you have information which either confirms or contests the facts or, more particularly, any conclusions presented, I'd like to hear about it (especially if your feedback includes data references). I can be contacted at ian@thermoguard.com.au .

