POINT AND SQUIRT

Novel, and mostly unproven, drivelines are making headlines, but development of diesel engines continues to meet a variety of environmental, legislative, and economic considerations. Fuel injection is key here, as Richard Simpson reports

While 2040 has been set as the end of diesel truck production in Europe, the technology continues to evolve. New Euro VII limits for heavy-duty diesels are expected to be finalised this year, and be introduced on production vehicles in 2025. They will aim for the virtual elimination of all harmful exhaust: tackling a spectrum of gases and other substances including ammonia, methane, and volatile and semi-volatile particles in addition to the currently regulated 'solid' particulate matter. Individual limits for nitrogen dioxide (NO_2) and nitrous oxide (N_2O), which are currently lumped together as NOx, are expected. There will also be limits on CO_2.

These limits will apply for the life of the engine, and must be achieved in the 'real world' under all conditions rather than in lab tests.

While the complex exhaust aftertreatment systems which took the industry to Euro VI will still have their place, the emphasis is likely to switch back to the combustion chamber, and here fuel injection is the key.

Imperfect injection is a major cause of exhaust pollution. Large droplets of fuel burn incompletely, and get ejected as soot. Air that has not been mixed thoroughly with fuel forms pockets within the combustion chamber, and high temperatures make this atmospheric oxygen and nitrogen combine to form NOx gases.

So, the key is to control the injection of fuel into the combustion chamber. The smaller the droplets, and the more completely they can be dispersed the better. This means raising injection pressures, and controlling the injection events as precisely as possible. Common-rail systems, where the fuel is stored at pressures measured in thousands of bar upstream of the injectors, were introduced to truck engines in the mid-1990s, with Nippon Denso being an early supplier to Hino Motors. The precise dispensing of fuel through ever-finer nozzles closed by ever-smaller needles has been a continuing trend (BorgWarner's F3 system, pictured above, uses a needle just 1mm in diameter – below). Electronic control for injectors pre-dates this, with Detroit Diesel introducing it in the mid-1980s. Common-rail offers consistent fuel pressure independent of engine speed or load.

The technology has now evolved to a stage where multiple injections of fuel can be performed in a single combustion event. Injectors are now actuated electronically, and finely controlled via the engine's ECU. Vehicles monitor their own exhaust gases and adjust individual injectors to ensure the required 10 year/one-million mile compliance.

HOW IT WORKS

Typically, in an engine such as Volvo or IVECO, where SCR is the dominant form of NOx control, a small abrupt pre-combustion pulse of fuel is introduced to the cylinder ahead of the main event, which is a much larger and longer injection where the flow rate rises progressively. The intention is to mix the fuel as thoroughly as possible with the air.

Engines more reliant on EGR demand a larger initial pre-combustion injection followed by the main injection with as near a vertical rise in fuel flow as possible. Main injection is followed by a small post-combustion injection of diesel, which serves to reduce the extra particulate matter in the combustion chamber by burning soot particles.

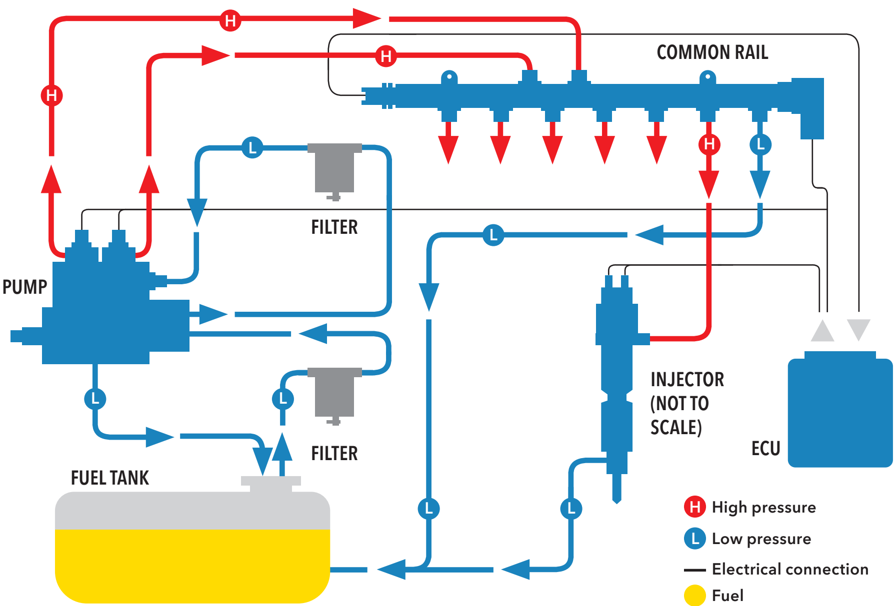
"The evolution towards very accurate on-board monitoring of emission has been a driver to develop a closed loop control system"
BorgWarner

Pre-combustion injection pulses reduce engine noise, while post-combustion injection pulses reduce particulate matter emissions.

Such technology, using two or three pulses, has got us to Euro VI E. But Euro VII, coincidentally, may require as many as seven injection pulses per combustion event.

Delivering multiple injections after combustion could help maintain the performance of emissions control systems. Late in the combustion stroke they raise the temperature of the exhaust gas, and if triggered at the start of the exhaust stroke they increase the amount of unburned fuel reaching the diesel oxidation catalyst and PM filter, which then 'light off'.

Multiple pre-and-post combustion events could also yield fuel savings and hence achieve CO_2 reductions.



COMING SOON

What have the fuel system manufacturers got in store as Euro VII approaches? They are understandably tight-lipped. Bosch states: "The latest Bosch modular common rail system selectively consists of the so-called CRIN L/C injectors, the high-pressure pumps CPN6/CB6, and the hot-forged rail HFRN. The Bosch system allows pressure ranges from 1,800 up to 2,500bar, and it is designed for engines with up to eight cylinders and a service life of up to 1.6m km, depending on the requirements.

"An improved high-pressure diesel fuel pump and a leakage-free injector design reduce the drive power demand and thus improve efficiency. One of the main features of the injectors is their capability for high nozzle flows, which allows an improved injection strategy, an optimised combustion and improved performance of the engine. The system is controlled by our engine control unit MD1."

Bosch technology is used in a landmark engine launched in China last year, to little acclaim in Europe. Manufacturer Weichai Power broke a significant barrier in truck engine design by producing a 13-litre unit with a thermal efficiency exceeding 50%: comparable European engines' efficiency is around 46%. Carefully matching air flows and combustion-chamber shape with fuel injection increased combustion speed by 30%.

CHANNELLING THE FLAME

A novel diesel injection technology is currently being researched in the USA by Charles Mueller at Sandia National Laboratories: channelling technology from the humble laboratory Bunsen burner! Tubular shrouds are fitted to the injector's outlets, and like the tube of a Bunsen burner with the air hole open, draw air into the high-speed flow of diesel droplets using the Venturi effect. The resultant thorough mixing of fuel and air results in cleaner and more complete combustion, boosting efficiency and reducing emissions. Ford and Caterpillar are both supporting the research into what's been dubbed 'ducted fuel injection'.

BorgWarner, which now owns the British-based former Delphi operation, said: "The new BorgWarner F3 system features the DFI21 diesel injector. This has been designed to offer maximum flexibility to engine manufacturers to optimise combustion performance and efficiency. The new nozzle control valve is at the heart of the injector: it is designed for pressure of 2,500bar and above, has been miniaturised to minimise leakages, and to reduce the control volume inside the injector: this low mechanical and hydraulic inertia result in a very fast injector, for excellent multi-injection performance allowing combustion improvements.

"The evolution towards very accurate on-board monitoring of emissions has been a driver to develop a closed-loop control system. The injector is fitted with a header containing electronics and an accelerometer; the ECU communicates with the header in between injections using injector drive wires. The benefit is the ability to accurately detect needle events for independent monitoring of injector timing, and to activate fuelling compensation strategies over the life of the engine." TE