Cooking with gas

John Coxon reports on how a new approach is allowing one motorsport team to get the best out of LPG fuel

With its primary focus on entertaining the spectators, the British Touring Car Championship (BTCC) isn't where you would expect to see revolutionary change. The UK's premier saloon car series is surely more about marketing than technology, yet in its own way the category has been responsible for more technology innovation in the past five years or so than perhaps just about any other racing category the world over. Having finished its love affair with the diesel and quietly forgotten (for the time being) its campaign on exhaust emissions; the latest of these has been the introduction of LPG or liquefied petroleum gas.

LPG is nothing new in motorsport nor is it new to the BTCC. About 12 years ago, Vauxhall introduced it as a prototype offering to a one-make series based around the V6 Vectra SRi. Rumoured to be using a different camshaft and better exhaust the car was, not surprisingly, highly competitive. In 2004, John George used the fuel to indifferent effect in the BTCC but this underfunded team had unfortunately fully underestimated the effort required to be competitive in this category.

So when the highly respected Mike Earle's Team Aon Ford Focus announced earlier this year that it was to use the fuel, there were many who just simply wondered. Of course David Mountain, founder of Team Aon engine supplier Mountune, and general manager Roger Allen, when approached by Earle and fuel supplier Calor Gas, could see beyond the significant sponsorship available. A Motor Octane Number of about 96 compared with that of the BTCC-spec fuel of about 90 was sure to give some advantage, but in order to get the necessary raw engine power an approach totally different from that of the John George effort was needed.

It was a difficult year for Team Aon in 2009. Expectations were high in its first year of competition but in mid-season, when progress was slow, Mountune and its ten years of experience of the 2.0 litre Duratec engine were brought in to assist in the engine's development. It had only three weeks to produce a new engine, yet by the end of


Fig. 1 – Brands Hatch winning LPG 2.0 litre Duratec engine

the season the team had managed to haul itself towards the front end of the grid.

For 2011, however, with BTCC engine regulations moving towards 2.0 litre turbocharged units in the form of the NGTC (Next Generation Touring Car) regulations, there seemed little point in refining the current unit for only one year. With the Swindon Racing-produced NGTC unit rumoured to be based on a GM product, this option was not open to Mountune since Ford, although not involved in any financial way has strong business links with the company and supplies invaluable technical information to the team.

So the only way would be to develop their own NGTC engine based on their current Duratec unit (Fig. 1). Also, with the agreement of Alan Gow and Peter Riches at BTCC organiser TOCA, who stipulated certain 'hard' points – namely a valve lift no greater than 11mm, a maximum compression ratio of 11.0:1, 0.8 bar (11.6 psi) of boost and a maximum rev limit of 7000 rpm – the LPG project was born.

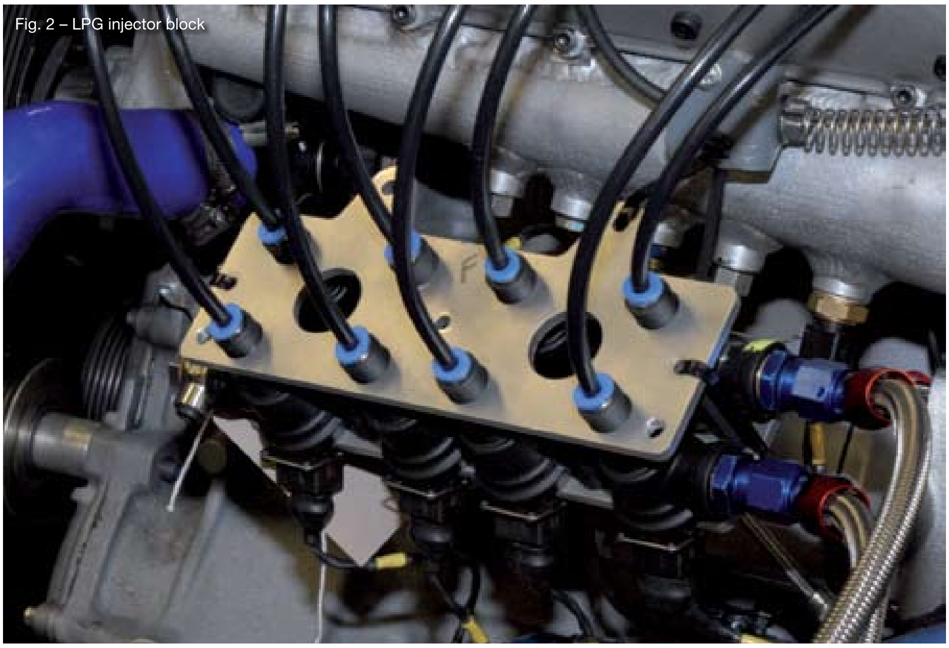


Fig. 2 – LPG injector block

"A fundamental decision made right from the start was that in order to get the power, the fuel had to be injected in liquid form," says Allen. "The use of a vapouriser to evaporate the fuel before injecting it as a gas displaces valuable intake air."

Early attempts at injecting the fuel using the normal gasoline approach with top-feed injectors attached to the side of each intake runner gave all manner of piston problems, resulting in the loss of two engines early in the development phase. Although Mountune never truly got to the root of the problem, the suspicion was that by injecting the fuel so close to the intake, liquid fuel was somehow hitting the piston, subjecting it to a thermal shock and then washing the lubricant off the cylinder bores. Unlike gasoline, LPG has no additives to assist upper cylinder lubrication.

In the short time available before track testing began for the 2010 season, the team therefore turned to LPG specialist Prins Autogas in the Netherlands, which came up with a totally different approach (see below). After this the problem disappeared. As Mountain says, "We did as they recommended and the problem just vanished. We haven't really gone back to it (the initial design) to see if it was the spray pattern or the position of the injector itself along the intake runner. We were just so relieved and happy to get over the problem. And we had the first of the track tests the following week!"

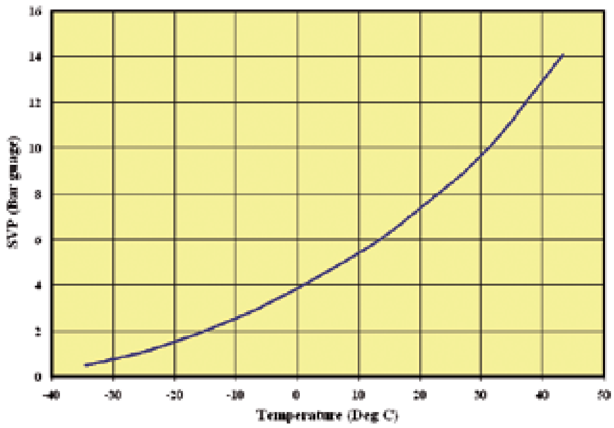
The system advised by Prins was a prototype liquid injection version using a unique, custom-built turbine fuel pump mounted in the high-pressure LPG fuel tank. Delivering a constant flow of fuel to the injector block, another line returns any excess back to the tank. Instead of delivering the fuel to a fuel rail clamped across a series of top-feed injectors, Prins considered it easier to suggest an injector block, which carries all eight injectors required for the four-cylinder engine (see Fig. 2). These are side/bottom-fed injector units each having a maximum flow rate of 2.5 grammes per second at a pressure about twice that of normal gasoline systems, somewhere around 7-10 bar

At the time, this was the largest liquid injector available and therefore required two per cylinder to match the airflow of the turbocharged unit. Although the series-mandated Cosworth Electronics (formerly Pectel) SQ6M engine controller can easily cope with twin injectors per cylinder, issues with the fuelling map where the second injector cuts in have necessitated a new larger design to be commissioned which is capable of 3.6 grammes per second. These should be available in the second half of the season and should simplify fuel mapping.

Interestingly, twin injectors per cylinder are specifically banned by the BTCC regulations on the grounds that in certain applications a performance advantage could be gained. Requesting a temporary dispensation from Gow and Riches, the team agreed to inject the two at the same position in the manifold, thus giving no perceived advantage.

The bottom fed injector has a distinct advantage when flowing LPG. Irrespective of which gas may be used (see sidebar), LPG needs to be stored under pressure if it is to remain in its liquid phase. At 25° C (77° F) the saturated vapour pressure (boiling point) of propane is about 8.5 bar (123 psi) At 40° C (104° F) this rises to 13 bar (188 psi) (see Fig. 3). Keeping the bulk fuel temperature as low as possible in the supply ▶

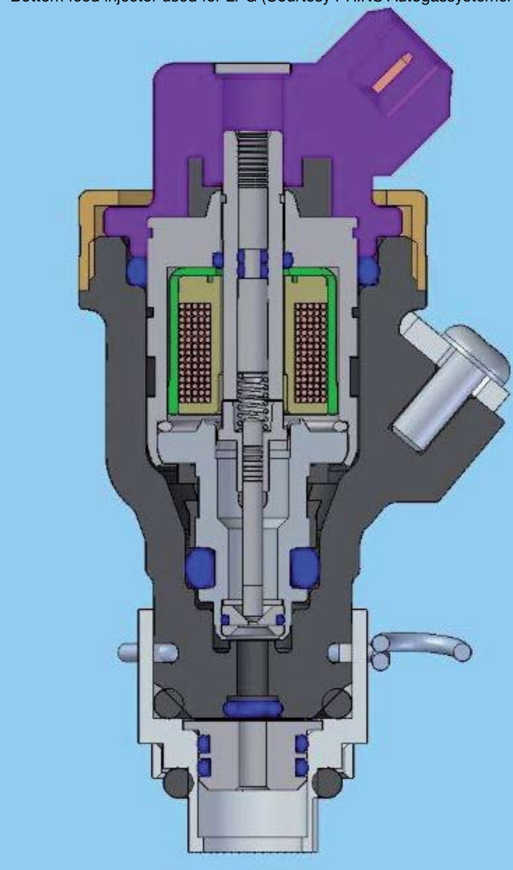
Fig. 3 – Saturated Vapour pressure curve for propane



lines is therefore essential.

Injectors of the type described are low impedance and energised by what is referred to as a 'peak and hold' electrical signal. This uses a large current to move the injector pintle quickly off its seat but once fully open, reduces it sufficiently just to hold it in place. This not only reduces the overall energy required to operate the system but also keeps the heat generated to minimum levels.

Fig. 4 – Bottom feed injector used for LPG (Courtesy PRINS Autogassystemen)



In keeping the fuel away from the solenoid coils, as in the case of a bottom feed design (see Fig. 4), the fuel remains cooler and vapour is much less likely to be created. Of concern in gasoline injectors, this is imperative when using more volatile LPG gases. But if keeping the fuel cool enough to prevent vaporisation is one thing, keeping it warm enough to vaporise when starting from cold would seem to suggest the opposite. Most LPG engines are bi-fuelled and start on normal gasoline before transferring to LPG when fully warm. In the case of a dedicated race engine this is not possible, however, so the injectors are placed in a position just behind the engine radiator where heat from the pre-warmed engine can help initial firing. Despite being fully pre-heated, dedicated LPG engines can take some time to fire up when cold.

Once the fuel has passed through the nose of the injector, much like some mechanical fuel injection systems, it is delivered to the

"Despite being fully pre-heated, dedicated LPG engines can take some time to fire up when cold"

WHAT IS LPG?

Fig. 6 – Properties of LPG gases

		Propane	Propene	n - Butane	iso-Butane	Butenes
Lower heating value	(MJ/kg)	46.3	45.8	45.7	45.6	45.3
Density	(kg/L)	0.5	0.52	0.6	0.55	0.61
Energy density	(MJ/L)	23.2	23.8	27.5	25	27.6
Boiling pt.	(deg C)	-42	-47	-0.5	-12	-10
Motor Octane No		96	84	89	97	77

LPG is not the same the world over. The result of 'waste' gases from the purification of mains, natural gas or a by-product from the petroleum refining industry, LPG refers to mixtures of propane (C3H8), propene (C3H6 – sometimes known as propylene), butanes (C4H10) and various butenes (C4H8). Sometimes small amounts of ethane (C2H6) may also be present.

LPG is generally used for its heating value in commercial cooking, domestic heating and fuel for industry, and while this is almost independent of the precise gas used (see Fig. 6) the make-up of the fuel will often depend on the ambient temperature at the point of use. In Europe, for instance, those countries having colder climates will have a higher proportion of propane and propenes in order to supply a higher vapour pressure. In the warmer, more southerly climes, however, butanes and butanes may be more commonly found.

But when used as a vehicle fuel, the critical factor is more one of octane (or anti-'knock') and so the exact composition of any LPG fuel used is critical. The characteristic used for this comparison is MON or Motor Octane Number. Although it is debateable how relevant this factor is for high-speed engines, of the fuels mentioned propane, (at 96) and iso-butane (at 97) have the highest values. All the others – propene, n-butane, and the butanes – have far lower MONs and therefore, unlike when used solely for heating, their inclusion as 'impurities' as a race fuel are not desirable.

So while it could be argued that in ordinary unmodified road transport vehicles (designed for MONs much nearer 86) LPG blends of propane and iso-butane can be considered to be rather a 'waste' of 'knock' performance, in racing engines this extra potential power can be harnessed by increasing the compression ratio or, in super/turbocharged engines, increasing the boost. With BTCC engine regulations in 2011 moving towards 2.0 litre mildly turbocharged units, LPG might just be an inspired choice of fuel.

In the UK, however, home of the British Touring Car Championship, commercial LPG as specified by the BS EN 4250:1997 standard is about 96% propane, while that used by the Team Aon Ford Focus is slightly higher and, more important, consistently higher at 98%. But for that little bit of extra performance as well as requiring a lower pressure to prevent vaporisation in the fuel lines, iso-butane would surely have been more desirable?

“Running the engine with LPG gives just that little bit extra power for an additional 5-degrees of ignition advance”

ENGINE SPECIFICATION

2.0 litre Ford Duratec prepared by Mountune

Bore:	87.5mm
Stroke:	83.1
Capacity:	1999 cc
Compression Ratio:	10.0:1
Fuel:	Calor Gas – 98% propane
Injectors:	Prins Autogassystemen
Camshaft:	Mountune Cams by Piper – max lift 11 mm
Valves:	Supertech Inlet – 35 mm Exh – 30 mm
Valve Springs:	Kaufmann
Pistons:	CP Pistons
Con Rods:	Carillo
Crankshaft:	Arrow Precison
Turbocharger:	Garrett T28 roller bearing supplied by Owen Developments
Turbo wastegate:	Tial – 0.8 bar boost max
Exhaust:	Simpson Race Exhausts
Intake restrictor:	37 mm diameter

point of injection via a black PTFE-type tube. Unlike mechanical systems though, there is no spray nozzle at the end of it and the 6 mm diameter tube with a 1 mm hole through which the liquid fuel travels, just terminates at the entrance to the intake runner. The thinking goes that the LPG fuel, while remaining liquid for most of its travel in the pipe, simply vaporises instantly upon emerging into the engine intake air stream. No matter what the theory states, in practice the system would seem to work very well and has the further advantage of being a fairly quick exercise to optimise the precise point of injection as well as interrupting the flow of intake air as little as possible.

When it comes to the timing of the injector pulse relative to the other events in the combustion cycle, this was found to be even less critical than in a gasoline engine. “The liquid is supposed to vaporise instantly as it leaves the injector, so I’m not sure it would make any difference at all,” says Mountain. In the case of ignition timing, he explained, back-to-back tests using an engine with a fixed compression ratio would enable a greater level of ignition advance when the engine was limited by ‘knock’. This is because the octane level in LPG is higher and the detonation limit is more advanced, enabling more ignition advance to be dialled in. As with most competition turbocharged engines, he further revealed, the LPG Focus turbo unit is also ‘knock’ limited and so running with LPG gives just that little bit extra power for an additional 5° of ignition advance.

We won’t of course talk about outright engine power because, although important, it is primarily the low-speed and mid-range torque of a turbocharged engine that can give it the advantage – an advantage that was apparent in the mixed wet-dry conditions of the Brands Hatch rounds when the cars won two out of the last three races. With the engine pulling cleanly from 3500/4,000 rpm right up to the (TOCA) imposed limit of 7000 rpm, drivers’ reactions were apparently initially guarded. Throttle response was of some initial concern since no anti-lag system is fitted (or allowed), but once the drivers became accustomed to the characteristics, and especially when they started winning, these concerns simply evaporated, you might say.

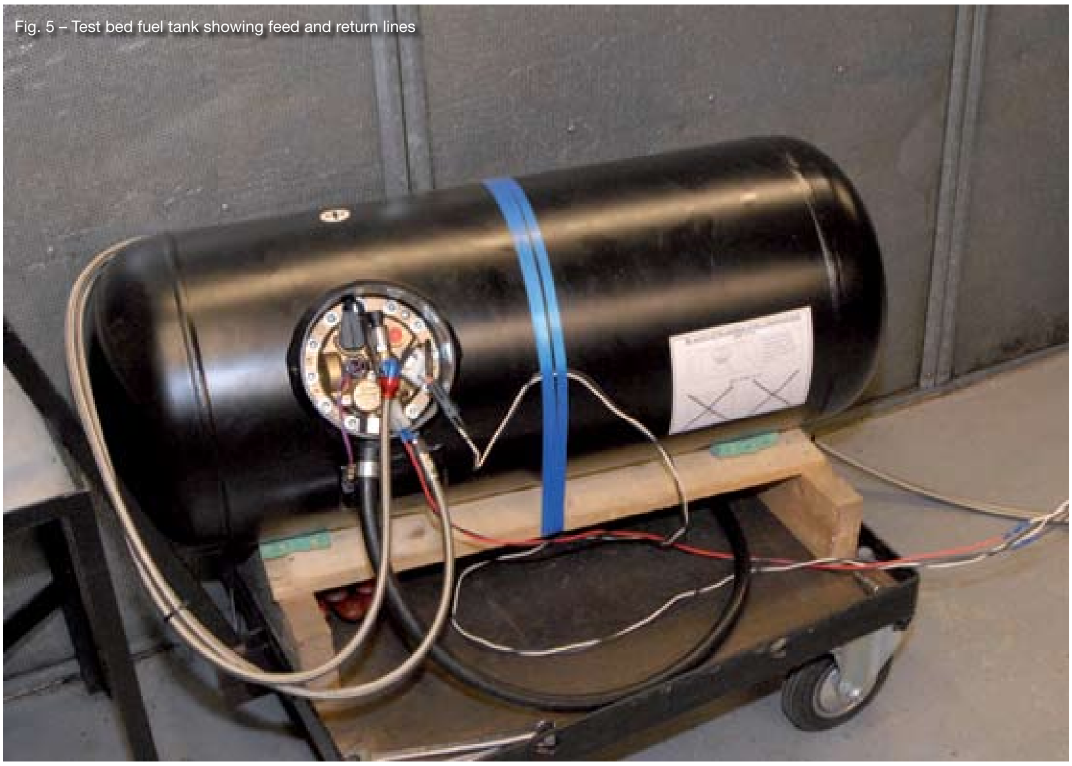


Fig. 5 – Test bed fuel tank showing feed and return lines

But winning brings with it closer scrutiny. Describing the LPG engine as very much ‘work in progress’, series organiser Gow announced the imposition of a 37 mm air restrictor from the next rounds at Oulton Park in June, reducing the outright power of the unit, Mountain claims, “by around 20 bhp”. At the time of writing, this gives Mountain and his team just over three weeks to incorporate a restrictor into the turbo inlet and re-map the engine. Since this engine is now in effect air-restricted the cam timing and intake manifold may also need to be re-optimised.

No-one ever said being at the front was easy. ■