Note 58-2

Petrol development for commercial auto and military aero use

At the date of the Ricardo fuel tests in 1919 the search was already in progress for improvement in petrol anti-knock quality by crude oil source and by mixtures with benzole and alcohol. It continued with additives culminating in Tetra-Ethyl-Lead (TEL) (see Sub-Note A), in production by 1928, and better refining methods. These efforts raised petrol Octane Number (ON), the anti-knock scale defined by Edgar in 1927 (729) from a retrospective 40-to-50 pre-WW1 to 80 for the best commercial auto fuel and 100 for military aviation use at Stoichiometric Air/Fuel Ratio (SAFR) by 1937.

Rich mixture gain

It was then found in the UK that this 100ON fuel *in pressure-charged engines when run very rich* (about 60% rich, i.e. AFR = 9.2 instead of the usual Normally-Aspirated (NA) maximum-power setting of 20% rich, AFR = 12.2) would cool the engine* and so resist knock sufficiently to permit much higher charge inlet pressure to be used than would be expected from the Octane rating determined in the standard NA variable-compression calibration engine (the CFR 3¼'' bore unit). The increased pressure was sufficient to give 30% more power and the Performance Number (PN) scale was then introduced to rate the fuel as Grade 100/130PN, the two figures representing ON with a lean mixture and the extra power available on rich mixture (592,599).

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*Samuel Heron wrote in 1961 "*The use of rich fuel-air mixture as a means of preventing cylinder over-heating is still thought by many engineers to be due to the cooling effect of the evaporating fuel. There is reason to believe that this view is incorrect and that the reduction of cylinder temperature with rich mixture is due to reduced flame temperature*" (1057).

Improved rating use

The use of this improved rating was just in time to have a significant effect in the 1940 Battle of Britain and Grade 100/130 (which contained 5 cc TEL per Imperial gallon, 0.11% by volume) remained the main combat fuel used by the Allies in WW2.

Further development of aero fuel

Further development provided by 1944:-

(1). The US Grade 115/145PN for the air-cooled Wright R3350 (cubic inch displacement) 18 cylinder radial engines of the Boeing B29 Superfortress in very-long-range bombing operations over the Pacific (599);

(2). The UK Grade 100/150PN (100/130 with the extra additive of 2½% Mono-Methyl-Aniline) for fighter use in the European Theatre, initially to pursue the V1 flying bombs (598).

Power gains with higher fuel ratings

The advantage to be gained by increase in fuel knock resistance , permitting higher supercharge pressure, was illustrated in (598) from tests on the liquid-cooled Rolls-Royce Merlin 60^0V12 aero engine of 27 litres:-

Test Date	Fuel Grade	Engine Mark	Max. Sea-Level HP obtainable 150 Hour Type-tested	
Early 1939	87ON	XII	1,150	Datum
End 1942	100/130PN	66	1,750	x 1.52
Late 1944	100/150PN	RM17SM	2,200*	x1.91

*A 15 minute test was achieved at the end of 1944 with the RM17SM on 100/150PN + water injection at 2,600 HP (Datum x 2.26).

Improvements followed the general process of (1) fuel of higher knock-resistance; (2) supercharger improvement to make use of the better fuel; (3) mechanical development to make the engine reliable at the higher power.

As an indication of development over 26 years, it is interesting to compare the above figures with the rating of the 1918 US Normally-Aspirated Liberty aero engine, also of 27 litres, which was 400 HP on (retrospectively graded) 58ON fuel (901 discussion, Rod Banks' comment).

Triptane

Late in WW2 small quantities of a new fuel, Triptane, were produced rated at 140/200PN or, with 0.1% TEL added, 200/300PN. Had military piston aero engines continued in front-line use no doubt means would have been found to increase the supply for combat.

Post WW2 aero

However, post-WW2 the gas turbine, needing no fuel knock-resistance and therefore able to burn kerosene, terminated the military need for high PN aviation petrol and, after piston engines were also phased out of scheduled civil air transport, 100/130 remained the standard for private general aviation use. A halved-TEL version was introduced in recent years for environmental-protection reasons .

Post WW2 auto

Commercial auto fuel improvement continued to a peak as “5 Star” of 102 Research* ON in 1961. This was withdrawn from pumps in 1975 and work from 1986 was aimed at achieving 96RON without TEL, both moves for protection of the environment.

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*The post-WW2 “Research” test (for RON) is run at lower speed and lower inlet temperature conditions in the calibration engine compared to the “Motor” test (for MON) and gives 7 to 10 ON numbers higher (610). Previous tests for ON are understood to be equivalent to MON (714).

Sub-Note A

The very-high value of Tetra-Ethyl-Lead (TEL) as an anti-knock additive was discovered in the General Motors research laboratories fuel section under its chief Thomas Midgely (or Midgley – references differ) and his assistant Thomas Boyd in late 1921 (592). It is more effective per unit mass than any of 46 other tested chemicals listed in a 1938 source (594, Table 10), far more than most. Ref.(592) says 30,000 compounds were considered by GM! Compared with 2 other additives which were marketed later, benzole and ethyl alcohol (the UK petrol brands with these additives were “National Benzole” and “Cleveland Discol”) TEL was x332 and x161 more effective, respectively. An addition of 2cc per Imperial gallon (2cc/Ig = 0.044% by volume) increased the ***zero*** Octane Number (ON) of Normal-Heptane to 40 linearly although the return decreased after that so that 5cc/Ig (0.11% by volume) achieved 55 ON (594 Fig. 104; these ON are retrospective to Edgar’s 1927 scale).

To prevent objectionable deposits and corrosion in the cylinder it was found necessary to mix TEL with Ethylene Dibromide as a scavenger of the combustion products.

The 1st use of TEL in motor racing was at the 1923 Indianapolis 500 mile event (6).

Enviromental objections

After 50 or so years of widespread use, however, TEL in auto exhausts started to be blamed for low IQ in children living near busy roads. Although the connection was later disputed and an alternative explanation of the problem provided, the use of TEL began to be restricted from 1978. Shell developed unleaded racing fuels over 1988 – 1991 (535) and FIA rules required such fuels after 1992. TEL was banned altogether from UK auto standard petrol from 1 January 2000.

It is now fashionable to ignore completely the power/weight and fuel economy benefits which were provided by TEL in high-compression or high-supercharged engines (such as helping to win the 1940 Battle of Britain) and disparage Midgely’s work (e.g. a newspaper article in 2000 headed “*The deadly Dr Midgely gets it wrong – again*” which added blame for the reported ozone-depletion effects of the refrigerator gas Freon to TEL (888)).

From the comfort and high degree of safety of a standard of living built on scientific and engineering advances it is quite usual nowadays to concentrate on the unforeseen (and unforeseeable) side effects of some of these advances - which have certainly *benefited* the lawyers – and to load all current research with every conceivable test against remotely-possible, if improbable, undesirable by-products. It has been said that if water were discovered today its unfortunate effects, in drowning, flood damage, ice and snow damage, iron rusting and timber rotting, would rule it out of use.

It only remains to be added that from 1979 up to 8% by volume of Methyl Tertiary-Butyl Ether (MTBE) was included in US gasoline to replace TEL for octane improvement, increased in 1992 to 15% to further oxygenate the fuel to reduce certain tailpipe emissions and meet 1990 legislation (creating "Reformulated Gasoline, RFG), that MTBE traces were then found to be polluting drinking water, that legal actions ensued claiming it to be carcinogenic and that California (always wanting to be forward in environmental issues) in March 1999 ordered it to be phased out of state fuel by end 2002 (later extended to end 2003)(893).Ethanol at 75% may replace it.

[Written originally in early 2003. The author has not attempted to follow later twists in this saga, which led to 6% of ethanol in state gasoline and even some use of 85% (!), only to note that in early 2012 California is causing complaints that it does not want US-grown corn-based ethanol but prefers sugar-cane based imports from Brazil, allegedly better for the environment – but also wants to get rid of any transport system which emits CO_2, thereby again upsetting the ethanol industry which expanded to serve their earlier enthusiasm.]