

Manchester XPAG Tests

Part 4 - The Problems with Modern Fuel (1)

Introduction

In the previous article, I described how the SU carburettor measured the volume of air flowing into the engine and mixed this with a metered volume of finely atomised petrol droplets to give a precise Air to Fuel Ratio (AFR). Investigating how modern petrol effects the operation of the SU carburettor was one of the objectives of the Manchester XPAG tests, specifically to determine the optimum needle profile to use with modern fuels. It was this data that confirmed two of the predicted problems caused by modern fuel. The first *Weak Running* is discussed in this article, the second, and more serious problem, *Slow Combustion* is discussed in the next article.

Air Fuel Ratio and Lambda

With non-ethanol blended petrol the theoretical Air-to-Fuel Ratio (AFR) is 14.7:1 i.e. at a ratio of 14.7 gm of air for every gram of petrol, all the oxygen in the air will be used by burning hydrogen atoms to produce water (H₂O) and by burning carbon atoms to produce carbon dioxide (CO₂). This ratio is referred to as the stoichiometric mixture. However, cars normally run with an AFR of between 12.5:1 and 13.5:1, i.e. with a mixture that is richer than the ideal. This is because some of the carbon burns to form carbon monoxide (CO) using only one oxygen atom rather than the two hence the need for more petrol.

Normally the term LAMBDA is use rather than AFR. This is the ratio of the AFR an engine is producing divided by the theoretical ideal. Numbers less than 1 correspond to a rich mixture and greater than 1 a weak mixture. Maximum power is produced with a Lambda of 0.95 or a slightly rich mixture.

Modern cars are fitted with lambda sensors, which work by measuring the levels of oxygen in the exhaust, enabling the fuel injection system to be continually adjusted as the engine is running. A similar lambda sensor was fitted to the test engine at Manchester and used to ensure the mixture was set at a lambda of 0.95 for every test by manually tuning the carburettors.

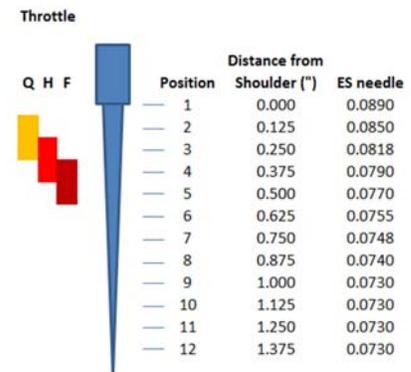
Standard needle profile

The height of the suction piston in the carburettor is a direct measure of the volume of air flowing into the engine and reflects both the throttle setting and engine rpm. The annulus between the tapered needle and the jet, at that height, determines the volume of fuel leaving the jet and hence the AFR. As more air flows through the carburettor the height of the suction piston increases, pulling the tapered needle out of the jet, increasing the size of the annulus allowing more petrol to leave the jet. The profile of the tapered needle sets the AFR for the different piston heights.

Simplistically, the suction piston will float at the same height when the engine is running at 4000 rpm on half throttle and at 2000rpm on full throttle. In both cases the position of the needle in the jet will be the same and so the carburettor will deliver the same AFR.

Needle profiles are identified by two or three letters. There is a reference booklet "*SU Carburettor Needle Profile Charts*" available from Burlen Fuel Systems that lists all the needles and their profiles.

The profile of a needle is define by its diameter at 1/8" steps down from the shoulder. The standard needle for the twin 1 1/4" SU carburettors fitted to the TB, TC and TD is an *ES* needle and its measurements are shown in the diagram. This also shows the approximate range of positions on the needle when running at quarter



(Q), half (H) and full throttle (F) up to 3750 rpm.

It is interesting to see the maximum piston height is only around 0.6" at 3750 rpm, full throttle and that normal road driving typically uses only the first 5 or 6 positions.

Measurements at Manchester

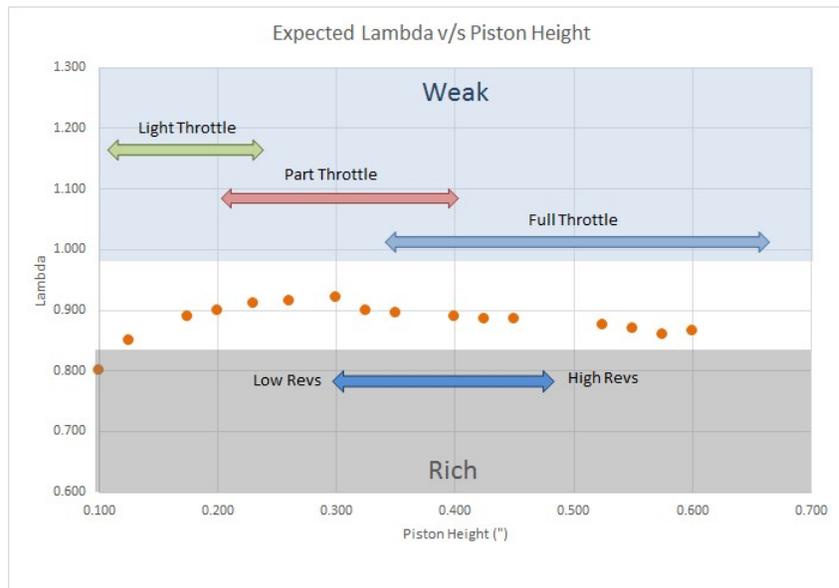
To determine the optimum needle profile a set of tests were run using different fuels, engine revs and throttle settings. For every test run, i.e. one fuel, one engine RPM and with one throttle setting, the carburettors were set to deliver a Lambda of 0.95 using jet adjusting nuts and the ignition timing was set to give maximum power. In other words the engine was fully re-tuned for every test run.

An indicator and a scale were fitted to the top of the suction chamber of each carburettor and the faces of the Jet adjusting nut were engraved with 1 – 6 dots to determine how many flats it had been screwed down. The combination of these two measurements give the position on the needle allowing the diameter of the needle necessary to deliver a lambda of 0.95 to be calculated.



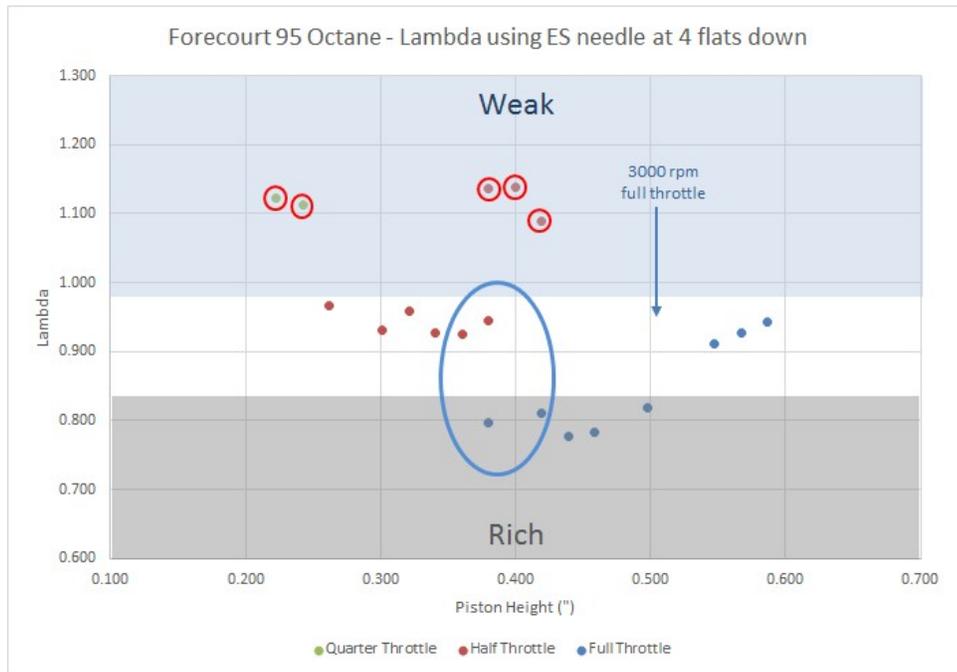
Running Lambda

The graph below shows an ideal plot of how Lambda would be expected to vary with carburettor piston height. Each dot represents an engine RPM / throttle setting that corresponds to that piston height. The white horizontal band is the ideal range for lambda. Lambda values greater than 0.98 represent a weak mixture and less than 0.83 a rich mixture.



At light throttle / low revs the mixture is set rich (left hand side of the graph) to give a steady tick over and smooth slow running. It is set slightly rich at part throttle, normal running conditions, becoming richer at high revs / full throttle as the unburned fuel, helps protect the engine by cooling the valves.

Even though Lambda was set to 0.95 for each test at Manchester, it is possible to calculate what Lambda would have been delivered if the engine had **not** been retuned. The graph below shows this data with the jet adjusting nuts set at 4 flats down from fully closed, running with a standard ES needle and using the same brand of 95 octane petrol.



The first thing to notice is this graph looks very different from the ideal above. It shows two surprising features that go a long way to explaining the problems people experience when using modern fuel, *Weak Running* and *Slow Combustion*. However, despite these anomalies, overall, the data shows that the *ES* profile needle is a good choice for the XPAG engine.

Weak running

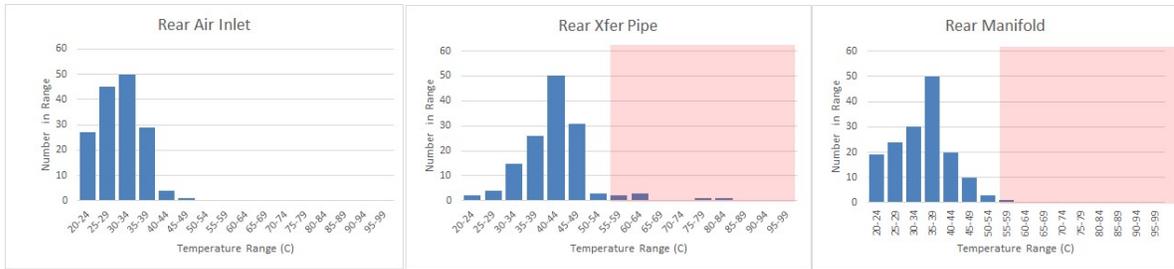
The five points circled in red (two green, quarter throttle and three red, half throttle), correspond to the carburetors delivering an exceptionally weak mixture. Indeed, had the carburetors not been retuned, the engine would not have started. Significantly, these 5 tests were run after the engine had been stopped for a few minutes to make adjustments.

These results clearly illustrate the FHBVC's fuel expert's prediction that it is possible for modern petrol to boil in the jet while the engine is running. The SU carburettor is a volumetric device, i.e. for a given volume of air entering the engine, it adds a fixed volume of petrol. When the petrol starts to boil, liquid and bubbles of vapour leave the jet which are less dense than just the liquid. As a result a lower mass of petrol is delivered into the air stream resulting in a weak mixture. Weak running further increases the engine's temperature and under-bonnet temperatures, resulting in more fuel to boiling, until the mixture becomes so weak the engine splutters to a stop. This scenario is typical of stop-start driving in a queue of traffic.

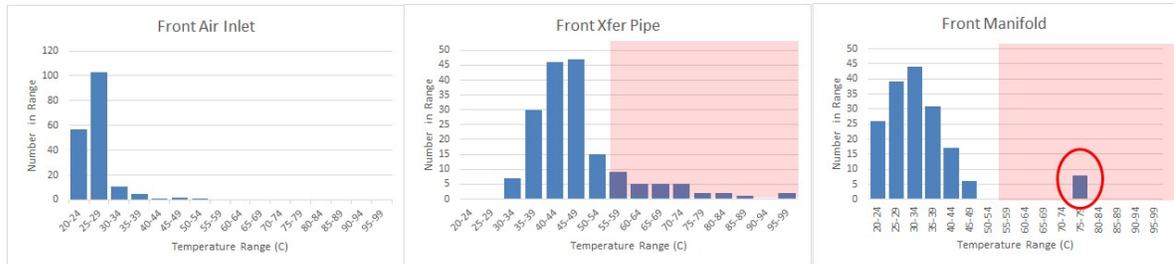
There are two main ways the petrol in the carburettor can be heated, by radiation and convection from the hot exhaust manifold that sits just below the carburetors and by conduction through the inlet manifold from the cylinder head. To measure the temperature of the petrol in the jet, sensors were fitted in the transfer pipe between the float chamber and jet of each carburettor (shown as xfer pipe on the graphs). Sensors were also fitted between the carburetors and inlet manifold, to measure the heat conducted from the engine, and to the inlet of each carburettor to measure the temperature of the inducted air.

The histograms below show the range of measured temperatures for all the tests. The red area corresponds to the temperature range where petrol vaporisation would potentially cause problems.

Rear Carburettor



Front Carburettor



While these do not reflect the temperatures that may be reached in an enclosed engine bay, they do show some interesting features.

The test engine was mounted on the dynamometer with no restrictions to air flow and, other than the exhaust manifold, with no hot areas near the carburettors. Unexpectedly, the temperature of the air entering the front carburettor was noticeably lower than that entering the rear carburettor (left hand graphs). This was possibly caused by air heated by the exhaust pipe which ran underneath the rear of the engine. These lower temperatures are also reflected in the manifold / carburettor temperatures (right hand graphs), showing that when the engine is running, the temperature of the inducted air is the main factor effecting the temperature of the carburettor body rather than heat conduction through the inlet manifold.

This finding suggests that where possible, the air inlet to the carburettors should be positioned to induct as cooler air as possible, perhaps even adding ducting to direct cold air to the carburettors.

The exceptionally high front manifold reading, shown in the red circle, corresponds to the half throttle tests, mentioned above where the mixture would have been very weak. The high manifold temperature of the front carburettor was the cause of this problem.

As only the front carburettor was affected and it is probable that when the engine had been stopped the inlet valve on either cylinders 1 or 2 was open. This allowed hot gases into the inlet manifold raising the temperature of the front carburettor and causing the petrol to boil. This observation is consistent with the heat soak tests, reported in an earlier article, which showed heat from the inlet manifold was the main factor in increasing the temperature of the carburettors after the engine had been stopped.

When stopping a hot engine with the intention of restarting it a few minutes later (e.g. when filling up at a petrol station), it may be worth revving the engine and turning off the ignition while it was still revving. Keeping the throttle open as the engine runs down will allow cold air into the cylinders which may prevent this problem.

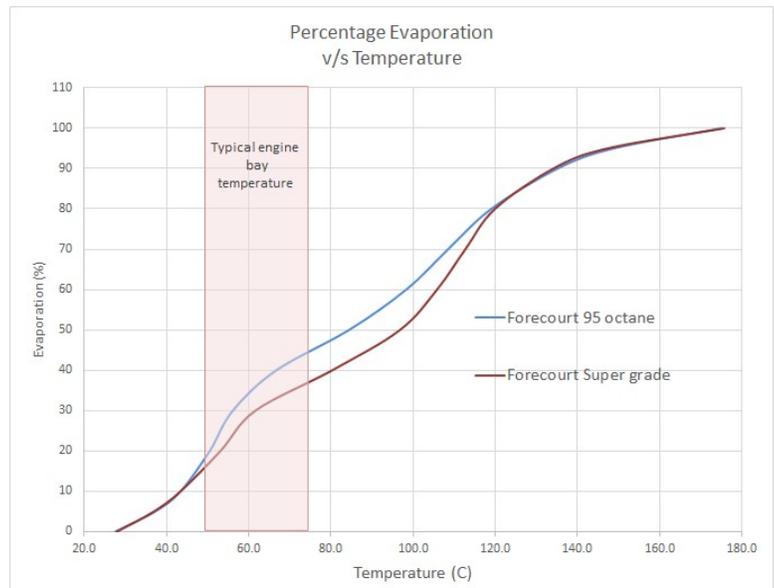
What is also significant is that the transfer pipe temperatures (middle graphs) were sufficiently high in some test runs to cause issues with vaporisation. However, other than the 5 weak running cases, highlighted above, weak running was not observed in any other tests. It is possible the fuel flow rate through the transfer pipe was sufficiently high that there was insufficient time for it to be heated before it reached the jet.

Furthermore, the temperatures in the front carburettor transfer pipe are noticeably higher than for the rear carburettor, demonstrating that, even in still air, there are measurable differences between the way heat is transferred from the exhaust manifold to the front and rear carburettors. While the reasons for this are not clear, it offers a possible explanation as to why some cars suffer from the hot restart problem and others do not.

Finally, there is an additional factor affecting this brand of 95 octane petrol, namely its volatility. Comparing the distillation curve for this fuel with that of a brand of super grade petrol shows the 95 octane petrol (blue line) is more volatile at typical under bonnet temperatures.

At the 75°C to 80°C temperatures of the front carburettor, 45% of 95 octane fuel would have vaporized compared with only 35% of the super grade fuel. This certainly would have made the weak running problem worse.

As the Manchester tests were run in March, it is possible this 95 octane petrol was “winter grade” which is why it was more volatile.



Slow combustion

The four points in the blue circle, on the above graph, show the carburettors delivering **different** lambda values for the **same** piston height. Simplistically, this is not possible as the volume of fuel is determined by the needle diameter at that piston height, i.e. same piston height, same volume of air, same volume of fuel, hence the lambda values should be the same.

This shows that at full throttle, there are combustion problems with modern fuel which will be discussed in the next article.

Conclusion

This data from the Manchester XPAG tests clearly demonstrates two problems with modern fuel that ultimately lead to the hot restart and “overheating” problems that many classic owners suffer from.

The transfer pipe temperature graphs show that the petrol in the carburettor can become sufficiently hot that modern petrol, which vaporises at lower temperatures than classic petrol, is susceptible to boiling - the cause of the weak running effect. Operating “so close to the edge” means that even a small temperature increase can have a disastrous effect, for example, when driving in slow moving traffic.

When an engine stops, the tests also show that hot gases leaking back into the carburettors from open inlet valves can make matters worse and are probably a significant factor that contribute to the hot restart problem.

These problems are made worse by the *Slow Combustion* problem that increases under bonnet temperatures, this is covered in the next article. Fortunately, the tests at Manchester have suggested ways these problems can be reduced. More to come.