Manchester XPAG Tests

Part 1 - Modern Petrol - Volatility

Introduction

Petrol is not a single substance, it is a mixture of many different hydrocarbons and additives. This mixture is very different from that supplied in the past changing petrol's physical properties and the way it behaves in an engine. One change is a difference in volatility which appears to be the main cause of the difficulties some people encounter using modern fuel in their classic cars, namely Overheating and Hot Restart problems.

Overheating & the Hot Restart problem

How many times have you heard people say "modern petrol makes my car overheat in traffic"?

In years gone by, when driving in slow moving or stop-start traffic, the temperature gauge would slowly creep up. As it reached 100^{o}C the water would start to boil and the engine misfire, eventually coughing and spluttering to a stop. With modern petrol this can happen long before the temperature gauge reaches 100^{o}C. While the symptoms are the same as classic overheating, it occurs when the engine temperature is still well within its normal running range.

The Hot Restart problem is related to Overheating. With a warm engine, after stopping for 5 minutes or so, the engine will refuse to restart, it just coughs and splutters. Wait of 15 or 20 minutes, the engine restarts without any difficultly. Both of these problems are caused by the low boiling point of modern petrol.

The dilemma is that not all vehicles suffer with these problems to the same extent. Sometimes you see, apparently identical models, one stopped with fuel problems, the other running perfectly well suggesting these problems can be avoided.

This article describes what causes these problems and what steps can be taken to alleviate them.

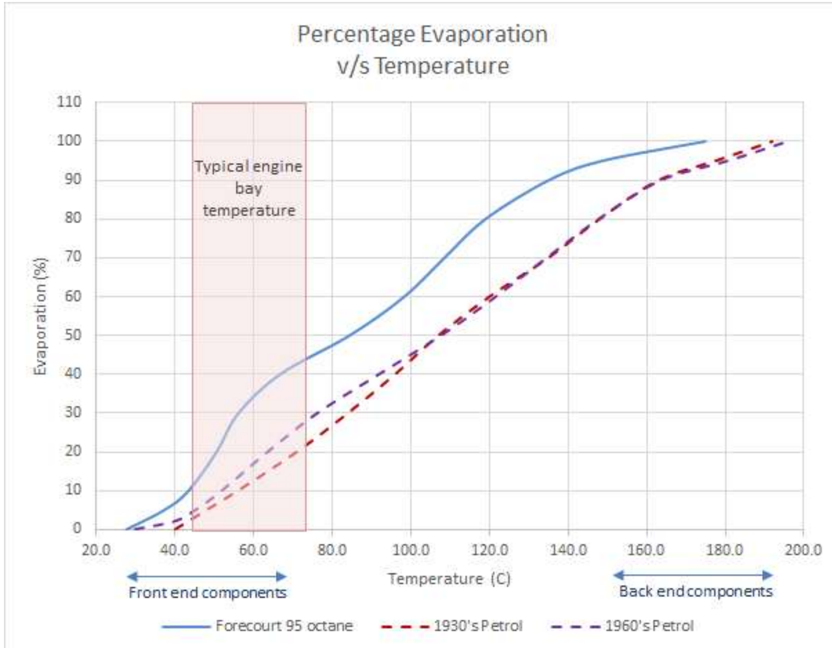
Petrol Distillation Curves

Petrol consists of over 300 different hydrocarbons, each with its own boiling point. If you heat a sample of petrol, the component with the lowest boiling point will boil first. Once this has evaporated, the temperature will rise until the boiling point of the next component is reached, and so on. Measuring the volume of fuel that evaporates as the temperature increases gives a distillation curve for that fuel. The components that evaporate at the lowest temperatures are called ***front end components***, those at the higher temperature, ***back end components***.

The way an engine starts, ticks over and runs depends on the shape of the distillation curve. However, just because two fuels have the same distillation curves does not mean they are chemically the same.

The Federation of Historic British Vehicle Clubs sponsored distillation tests on samples of the fuels used at Manchester.

The graph shows how much of the 95 octane forecourt petrol (blue line) evaporated as the temperature was slowly increased. It also shows the curves for 1930's and 1960's "classic" petrol (the red and purple dotted lines). They are both very different from modern petrol. At a temperature of 75°C 20% to 30% of the classic petrol would have evaporated. While at 75°C nearly twice that volume of modern petrol has evaporated.



With over 40% of modern petrol evaporating at typical under bonnet temperatures, it is surprising classic carburetted engines manage to run at all. Carburettors can only deliver the correct mixture when running on liquid petrol.

Engines and heat

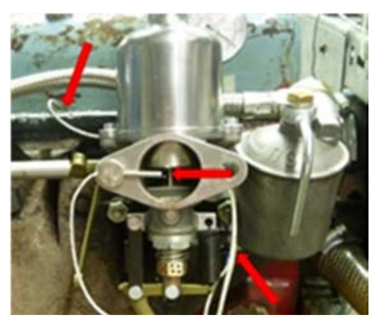
A petrol engine produces colossal quantities of heat. Unfortunately, only around one third of this heat energy is converted into power to move the car forward, the remaining two thirds is waste heat energy. A normally tuned XPAG engine produces 40 Kilowatts of power at full throttle (one third of the heat energy) and 80 Kilowatts (two thirds) of waste heat energy which just gets engine bay hot. Imagine a room in your house with 80 electric fires all switched on, it would certainly get very toasty! [Type a quote from the document or the summary of an interesting point. You can position the text box anywhere in the document. Use the Drawing Tools tab to change the formatting of the pull quote text box.]

In practice, approximately 55% of this waste heat is lost via the exhaust, heating the exhaust manifold, exhaust pipe and vented as hot exhaust gasses, 35% to the cooling system, 8% to heating the engine block and oil and 2 -5% through other means.

Manchester Temperature Measurements

Heat transfer to the carburettors and to the petrol was one of the measurements made at Manchester using 8 thermocouples attached as follows:

1. Fuel pump outlet to measure the temperature of the petrol flowing into the carburettors. Typically this was 22°C room temperature, corresponding to a warm summer's day.
2. Two thermocouples, one in each carburettor, were placed in the air inlet to measure the air temperature (shown in the picture). Typically this was 30°C. Again representative of an engine on a warm day.
3. Two thermocouples, one in each carburettor, at the bottom of the transfer pipe connecting the float chambers to the carburettor body (shown in the photograph on the right and the photograph below). Typically this was 42°C, which is surprisingly



Thermocouple in the air inlet and

at the bottom of the transfer pipe

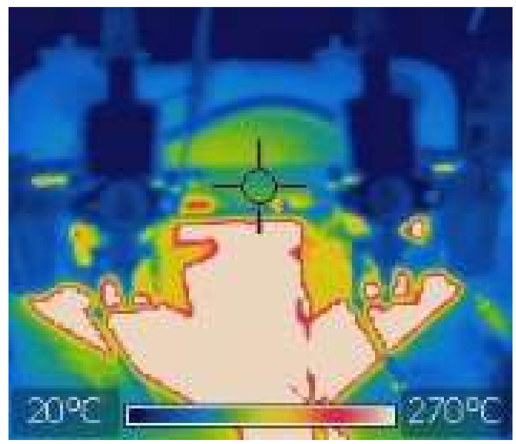
low considering this part of the carburettor is positioned under 1” away from the 400°C exhaust manifold.

4. Two thermocouples, one for each carburettor, embedded into an aluminium gasket that was fitted between the carburettor and inlet manifold to measure the heat entering the carburettors from the engine. Typically this was 36°C. These plates (bottom photograph) were also fitted with vacuum gauges to measure inlet manifold pressure.

Aluminum gasket with thermocouple

5. Finally, one thermocouple was fitted to the cylinder head between cylinders 2 and 3 (shown in the first photograph). Typically this was 170°C heated by the exhaust gasses passing through the cylinder head.

When the engine was running, the highest petrol temperature of 42°C was in the transfer tubes. At this temperature less than 10% of modern petrol will evaporate, insufficient to cause any problems. The low temperatures of the carburettors are shown more dramatically on the thermal image of the XPAG running at 3000rpm at full throttle.



The 20°C to 42°C carburettors and float chambers, shown blue, are silhouetted against the white (300°C plus) exhaust manifold. You can also see the pipe, also blue, that links the two carburettors looping over the top of the very hot exhaust manifold.

Despite being so close to the exhaust manifold and with no heat shield protecting them, the carburettors do not get excessively hot. The reason for this is simple. When the engine is running, especially under power, a large volume of petrol is flowing through the carburettors keeping them cool and this is why they are able to work with modern petrol.

However, looking at the thermal image above, the two choke levers below the carburettors are hot and shown as yellow with a red outline. Probably around 80°C. As these levers are connected to the bottom of the jets, they will certainly contribute to heating the petrol, particularly after the engine stops. Unfortunately, these did not have separate thermocouples fitted to them so it was not possible to track their temperatures.

Overheating & the Hot Restart Problem

When the car is in slow moving traffic or stopped, two effects work to increase the temperature of the petrol. Although the engine is running at low power and producing less heat, the rate at which heat is lost is greatly reduced as there is less air flow through the engine bay. The under-bonnet temperature will rise. In addition, petrol is flowing more slowly through the carburettors and has more time to heat up.

When the engine is switched off, petrol stops flowing and its temperature will continue to rise as heat soaks out of the engine, exhaust and radiator.

The distillation curve for 95 octane petrol (above) shows a rapid rise in the volume of fuel evaporating between 45°C and 70°C, the typical temperatures reached in the engine bay. As the petrol in the carburettors gets hotter, more of it boils. The pressure of this vapour forces petrol out of the carburettor jet, which collects in the inlet manifold making the mixture temporarily richer. The vapour bubbles in the jet then cause the carburettor to deliver a much weaker mixture when the engine is running or cranking. This is what causes the engine to stop or prevents it from starting.

The only solution is to lift the bonnet and wait for the temperature to drop. However, if the problem is not too bad, it is possible to nurse the engine back into life using the choke to enrichen the mixture. Although it will run very unevenly, driving a short distance will bring cooler petrol into the carburettors from the tank and the increased airflow will help reduce under-bonnet temperatures.

Modern cars do not suffer from these problems for two reasons. Firstly, the petrol in the pipes and injectors is held under high pressure, which increases the boiling point. Secondly, as soon as you switch the ignition on, the hot petrol in the engine bay is recirculated back to the fuel tank allowing the engine to start on a new charge of cold petrol.

What can be done to address this problem

There are basically four ways to address the Overheating and Hot Restart problems:

- Change the petrol you use
- Decrease the amount of heat generated by the engine
- Increase the heat removal from under the bonnet
- Reduce the amount of heat reaching the parts of the fuel system

Change the petrol you use

When I have suggested using a different brand of petrol in the past, I have met with comments like “all petrol is the same, how can using a different brand resolve my problem?” Nothing could be further from the truth, the composition of petrol from different sources is anything but the same. Not only does each brand use different additives, many also sell different grades of petrol. To further complicate the matter, the composition of petrol varies across the United Kingdom and over the time of year.

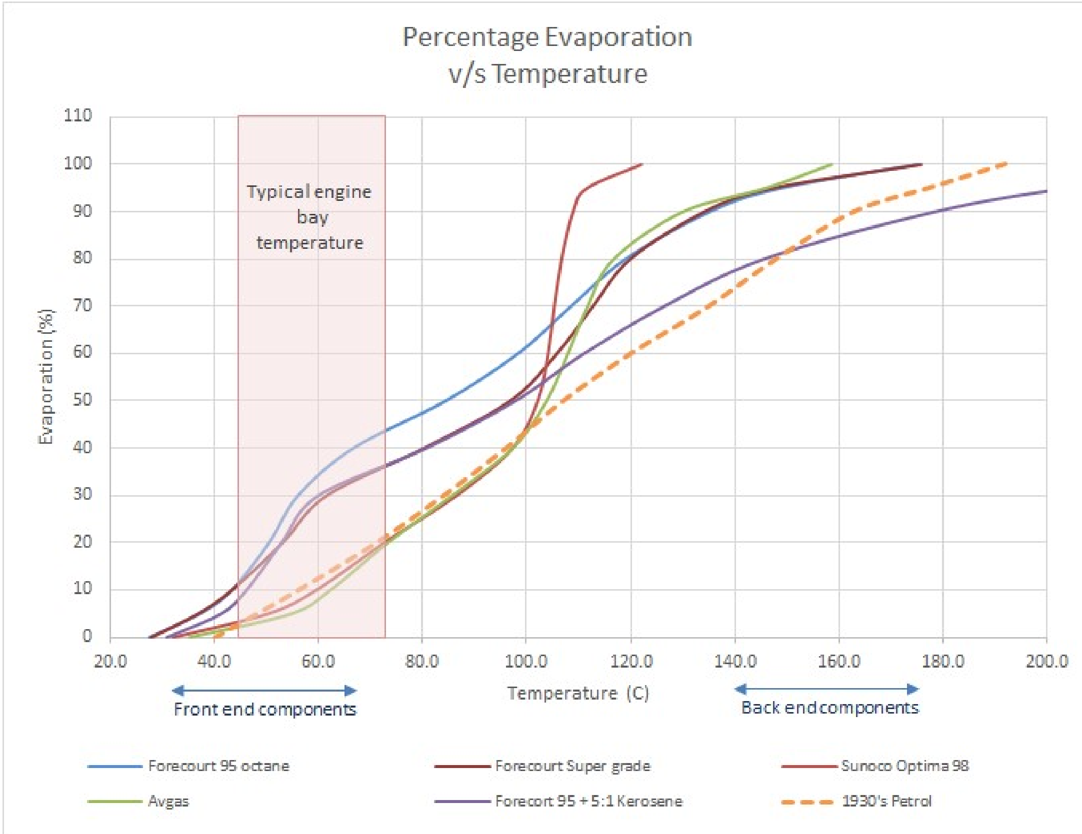
The UK fuel distribution industry is served by around 14 different refineries which supply petrol to their local area. Many of these came on stream in the late 1950s and early 1960s, reflecting the post-war demand for petroleum. The result is that no two refineries are identical. Petrol of one brand in one part of the UK most probably differs from the same brand in a different part of the UK depending on which refinery supplies those regions.

In addition, three different grades of fuel are sold throughout the year:

- Winter fuel - October to April. This has the highest front end components to ease cold starting and is what was used at Manchester
- Intermediate fuel - April to May and September to October
- Summer fuel - June to August. This has the lowest front end components and is the best fuel to use in a classic car.

In practice these dates are not fixed and will vary with ambient temperature and the turnover at any particular filling station, making it virtually impossible to know what grade of fuel is being sold.

The chart below compares the distillation curves of some of the different fuels used in the Manchester tests.



Fuels with lower front end components are less likely to suffer from the Hot Restart or Overheating problems, additionally, the test engine at Manchester also ran better on these fuels reducing the amount of waste heat produced.

The best fuels for a classic car are Sunoco Optima 98 from the Anglo American Oil Company and Avgas (a fuel for use in aeroplanes). Both these have considerably fewer front end components, more closely matching classic fuel below 100°C. Unfortunately, it is not legal to use Avgas in a road vehicle. While Sunoco Optima 98 is expensive, it could be considered as the fuel of choice for low mileage vehicles.

More practical solutions are to use Super grade fuels, or add kerosene (paraffin) which is legal for vehicles built before 1956 (a licence from HMRC is required). While these do not reduce the front end components as much as Optima 98 or Avgas they still improve the way the engine runs and make the petrol less susceptible to vaporisation. The curve shown above is for a 5:1 95 octane / kerosene mix. A 10:1 super grade / kerosene mix is preferred as this gives a greater reduction in low temperature volatility and a better overall match to classic fuels above 100°C.

Changing to a petrol that has lower volatility in the 45°C to 70°C range will result in less petrol evaporating at typical under-bonnet temperatures and is probably the most effective way to reduce the severity of the Overheating and Hot Restart problems. It is worth trying different brands, grades and filling stations to find out which petrol gives the smoothest performance and reduces petrol vaporisation problems. Perhaps regional car clubs could share members' experiences to provide practical local advice.

Regardless of which petrol you use, it is best to avoid filling your tank on the first run of the season, probably in April or May, when petrol stations are selling winter fuel. Only put in the fuel you need and fill up as soon as summer fuel becomes available. Otherwise, you could end up with a tank full of volatile winter or transition petrol on a hot summer's day, a recipe for problems!

Decrease the amount of heat generated by the engine

You can keep under-bonnet temperatures to a minimum by ensuring that your engine is properly tuned and runs at optimal efficiency. Remember cyclic variability from the first article? This can reduce an engine's efficiency by a few percent. Not sufficient to notice in everyday use, but a few percent of the 80Kw of waste heat is a lot of heat!

This will be covered in future articles.

Increase the heat removal from under the bonnet

35% of the waste heat is lost through the cooling system and it is important to make sure this is working to its optimum efficiency:

- Flush out the radiator
- Remove the flies and other debris from the radiator fins
- Check all the hoses are in good condition
- Ensure the thermostat is working properly
- Use a cooling system wetting agent
- Check your fan is fitted the correct way around. If the blades are dished, the convex face (outward bulge) should face the radiator
- Ensure your fan belt is in good condition driving the fan properly and not slipping

Ensure air can flow through freely the engine compartment:

- Remove leaves and other blockages such as badges from air intake grilles
- Ensure ancillary equipment such as the horn, wiring, etc. are not blocking the airflow, particularly around fuel pipes and carburettors

Electric radiator fans help keep air circulating but may make matters worse. In slow moving traffic, they are drawing hot air, probably in excess of 80°C, through the radiator and blowing it into the engine bay. Not ideal. It may be better to fit the fan at the bottom of the radiator, where the air is cooler or in a position where it can suck in cold air from the front of the car. I understand some people have also fitted 12 volt computer fans to blow cold air directly onto the carburettors.

One important point to remember is that hot air rises. Any fans, ducts or baffles intended to move cooler air through the engine bay should encourage this, not "fight it". Blow cold air in at the bottom of the engine compartment, extract hot air from the top.

It is also worth fitting a timer or equivalent circuit to ensure any electric fans continue to run for around 5-10 minutes after the engine has stopped as this will help alleviate the Hot Restart problem.

Reduce the amount of heat reaching the fuel system

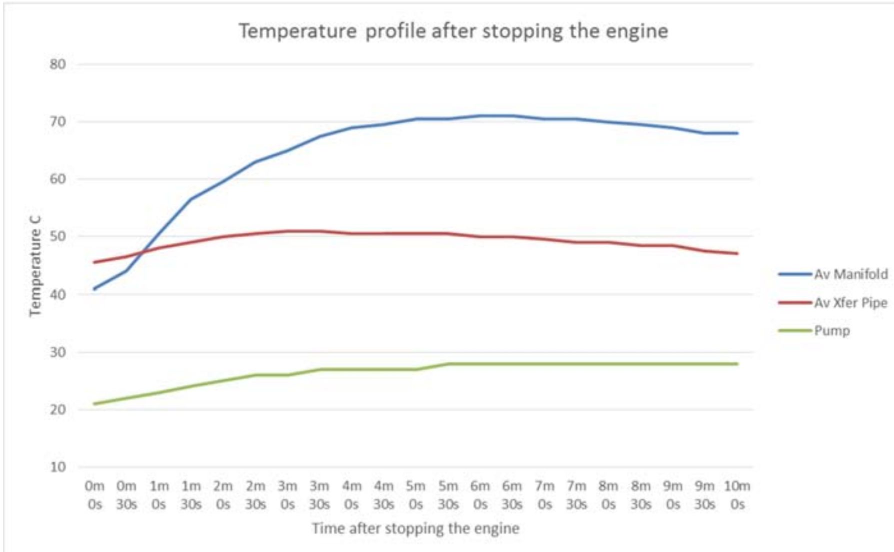
Anything that can be done to keep the fuel system, particularly the carburettors cool, will help reduce the severity of the problems caused by the volatility of the low end components in modern petrol.

Solutions worth consideration are for example:

1. Fitting electric fan(s)
2. A heat shield between the exhaust and carburettors
3. Thermal spacers between the carburettors and inlet manifold
4. Insulating parts of the fuel system
5. Adding baffles to redirect hot air around carburettors or fuel hoses
6. Insulating the exhaust manifold and front part of the exhaust system to reduce the heat they radiate under the bonnet

Unfortunately, insulation does not stop the transfer of heat, it only slows it down. Once the engine has stopped and the petrol is no longer flowing, the petrol will heat up, no matter how well insulated the parts of the fuel system are. Benefits will only arise if the heating is delayed for a sufficient time to allow the under-bonnet temperature to fall below 45°C.

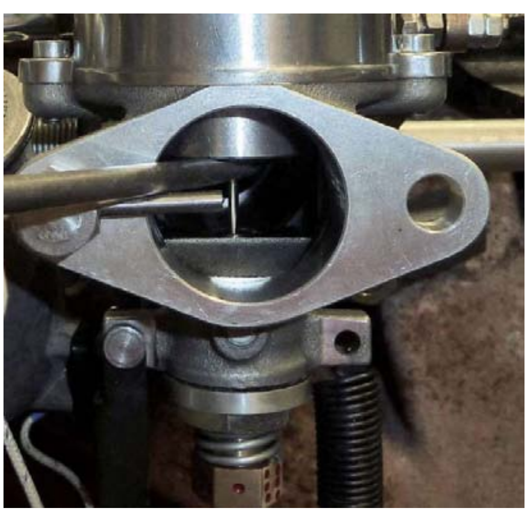
Unfortunately, not all "obvious" solutions are effective. At Manchester we insulated the bottom of the carburettor, the float bowl and transfer tube which are closest to the inlet manifold. This had no measureable effect on reducing the temperature of the petrol. After the engine was stopped temperature measurements below were taken every 30 seconds from the thermocouples on the fuel pump and carburettor to give the graph below:

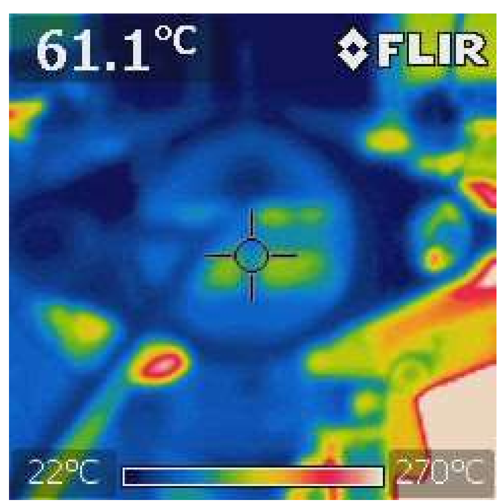


Three readings are the fuel pump (green), average of the two transfer pipes between the float chamber and carburettor (red) and the average of the temperature of the junction between the inlet manifold and carburettor (blue). As can be seen, the temperature increases of the pump outlet and transfer pipe were small.

The greatest temperature rise was seen at the point where the carburettor was joined to the inlet manifold. This was heated by conduction from the 170°C cylinder head through the inlet manifold and the hot gasses travelling back up the inlet from the valves. After 4 minutes, this raised the temperature of the carburettor to 70°C at which point 50% of the forecourt 95 octane petrol would evaporate. Sufficient to cause the Hot Restart problem.

The thermal image on the right below is taken looking down the inlet tract after the piston in the carburettor had been lifted with a screwdriver. It shows the hot gasses in the inlet manifold. The light blue area within the circle, the carburettor needle, is at an average of 61.1°C, the green area is hotter. This shows how the heat from the inlet manifold is significantly increasing the carburettor and petrol temperature.





This finding is not what would be expected and explains why the thermal insulation, mentioned above, had no effect. On the XPAG the reason why the carburettors get hot after the engine has been stopped is not because of their proximity to the inlet manifold but because the hot gasses escaping back up the inlet manifold.

A solution may be to blip the throttle and switch off the ignition while the engine is still revving as it will allow the hot gasses to be vented and cold gasses to enter the cylinders as the engine runs down.

The tests at Manchester were performed in a test cell, where the conditions are very different from an engine bay. For anybody wishing to investigate potential solutions, an infrared thermometer or, better still, a thermal imaging camera are the ideal way to identify hot spots. However, remember that as soon as the bonnet is opened, the temperature profile will change. As an alternatively, digital multi-meters with thermocouples are now inexpensive and provide the means to allow your passenger to accurately measure the temperature of parts of the fuel system even while a car is moving.

Conclusion

The Manchester tests clearly demonstrate that one of the problems of modern fuels is their low temperature volatility. While there is no magic solution to the Hot Restart or Overheating problems, it is possible to reduce their severity. While this article suggests steps that can be taken, there are be others that will be covered in later articles.

By using summer, super grade fuel with 10% kerosene added and ensuring the engine is optimally tuned, my TC does not suffer from the Overheating or Hot Restart problem even though I do not have a heat shield, insulation or an electric fan.

Paul Ireland