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MODERN PETROL – VOLATILITY – THE MANCHESTER XPAG TESTS

By Paul Ireland

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 and the Hot Restart problem

How many times have you heard people say "modern fuel 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°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°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 five 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 difficulty. 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 that, with care, these problems can be avoided.

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

Fuel Distillation Curves

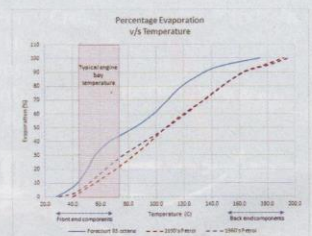
Petrol consists of over 300 different hydrocarbons, each with its own boiling point. If you heat a sample of petrol, the component with the lowest boiling point will boil first. Once this has evaporated, the temperature will rise until the boiling point of the next component is reached, and so on. Measuring 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 1930s and 1960s '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 nearly 50% of modern petrol evaporating at typical under-bonnet temperatures, it is surprising classic carburetted engines manage to run at all when you realise carburettors will only work with liquid fuel.



Petrol evaporation Modern vs Classic

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

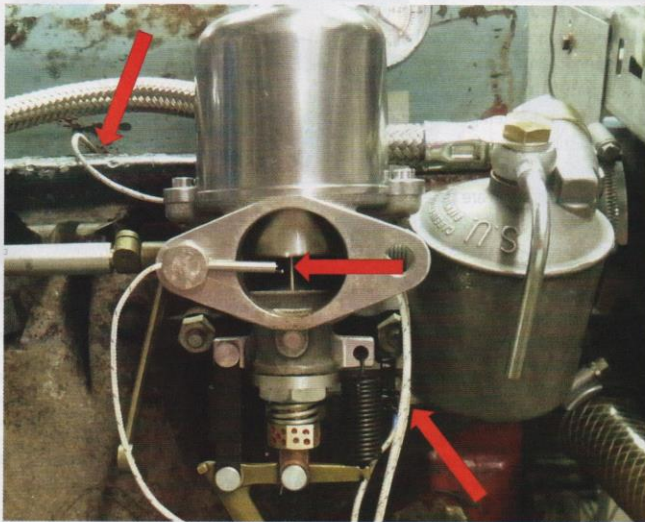
the heat energy) and 80 Kilowatts (two thirds) of waste heat energy. Imagine a room in your house with 80 electric fires all switched on – it would certainly get very toasty!

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

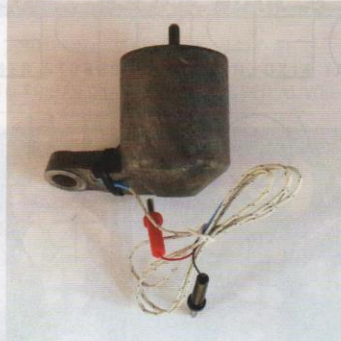
Manchester Temperature Measurements

Heat transfer to the carburetors and to the fuel was one of the measurements made at Manchester using eight thermocouples attached as follows:

1. Fuel pump outlet to measure the temperature of the fuel flowing into the carburetors. 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 below). Typically this was 30°C. Again probably representative of an engine on a warm day.



Thermocouples



Float



Plate

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 above and over the page). Typically this was 42°C, which is surprisingly low considering this part of the carburettor is positioned under 1" away from the 500°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 carburetors from the engine. Typically this was 36°C.

These plates (shown above) were also fitted with vacuum gauges to measure inlet manifold pressure.

5. Finally, one thermocouple was fitted to the cylinder head between cylinders two and three (large photo). Typically this was 170°C, heated by the exhaust gases passing through the cylinder head.

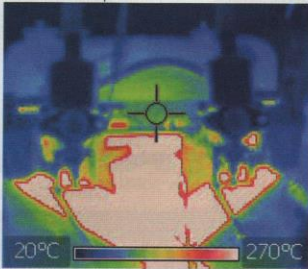
When the engine was running, the highest fuel temperature of 42°C was the petrol in the transfer tubes. At this temperature less than 10% of modern petrol will evaporate, insufficient to cause any problems. The low temperatures of the carburetors are shown more dramatically on the thermal image (over the page) taken of the XPAG running at 3,000rpm at full throttle.

The dark blue (20°C to 42°C) carburetors and float chambers are clearly shown silhouetted against the white (300°C plus) exhaust manifold. You can also see the blue pipe (cold) that links the two carburetors 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 carburetors do not get excessively hot. The reason for this is simple. When the engine is running, especially under power, a large volume of fuel is flowing through the carburetors keeping them cool and this is why they are able to work with modern petrol.



Carburettor setup



Thermal image

However, looking at the thermal image above, the two choke levers below the carburetors 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 these temperatures.

Overheating and the Hot Restart Problem

When the car is in slow-moving traffic or stopped, two effects work to increase the fuel temperature. Although the engine is running at low power and producing less heat, the rate at which heat is lost is greatly

reduced because there is less air flow through the engine bay. The under-bonnet temperature will rise. In addition, the fuel is flowing more slowly through the carburetors, so it has more time to heat up.

The distillation curve for 95 octane fuel shows a rapid rise in the volume of fuel evaporating between 45°C and 70°C, the typical temperatures reached in the engine bay. Furthermore, when the engine is switched off, no fuel is flowing and with nothing to remove the heat, under-bonnet temperatures will further rise as heat soaks out from the exhaust manifold, radiator and engine block.

As the fuel in the carburetors 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 you from restarting it.

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 enrich the mixture. Although it will run very unevenly, driving a short distance will bring cooler petrol into the carburetors from the tank and the increased airflow will help reduce under-bonnet temperatures.

Modern cars do not suffer from these problems for two reasons. First, the petrol in the pipes and injectors is held under high pressure, which increases the boiling point of the different components. Second, 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 fuel 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 distributor 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

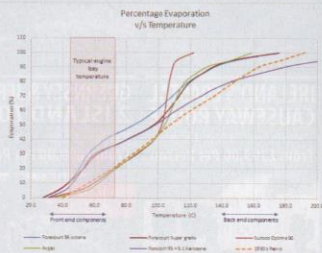
the post-war demand for petroleum. The result is that no two refineries are identical. Petrol of one brand in one part of the UK most probably differs from the same brand in a different part of the UK, depending on which refinery supplies those regions.

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 fuel turnover at any particular filling station, making it virtually impossible to know what grade of fuel you are using to fill your tank.

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



The distillation curves of some of the different fuels used

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.

These curves suggest that the best fuels to use 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 the curve shown above is for a 5:1 95 octane / kerosene mix, I use a 10:1 super grade / kerosene mix which gives a better reduction in low temperature volatility. Interestingly, adding kerosene gives a better volatility 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 until you find one that best suits your car.

Perhaps the most practical solution would be for the regional Centres and Natters to share members' experiences. Possibly even to establish a relationship with local suppliers or garage owners to find out which stations are selling summer fuel and when.

Regardless of which fuel 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 fuel 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 the future article on combustion.

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 dishd, 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 freely through 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 carburetors.

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 carburetors, cool will help reduce the severity of the problems caused by the volatility of the low end components in modern petrol.

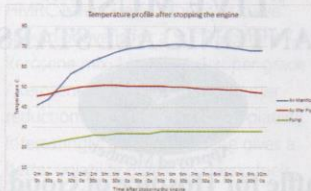
Solutions worth consideration are for example:

1. Fitting electric fan(s)
2. A heat shield between the exhaust and carburetors
3. Thermal spacers between the carburetors and inlet manifold
4. Insulating parts of the fuel system
5. Adding baffles to redirect hot air around carburetors 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 fuel 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 fuel. After the engine was stopped, temperature measurements below were taken every 30 seconds from the thermocouples on the fuel pump and



Temperature profile graph

carburettor to give the graph below:

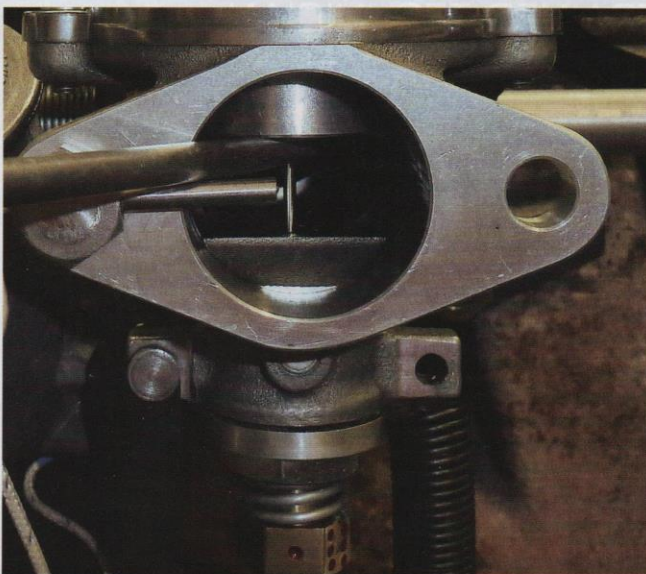
The three readings are the fuel pump (green), the average of the two transfer pipes between the float chamber and carburettor (red) and the average of the temperature of the junction between the inlet manifold and carburettor (blue). As can be seen, the temperature increases of the pump

outlet and transfer pipe were small.

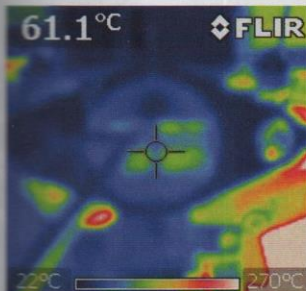
The greatest temperature rise was seen at the point where the carburettor was joined to the inlet manifold. This was heated by conduction from the 170°C cylinder head through the inlet manifold and the hot gases travelling back up the inlet from the valves. After four minutes, this raised the temperature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

The thermal image on the right is taken looking down the inlet tract after the piston in the carburettor had been lifted with a screwdriver. It shows the hot gases 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 fuel 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 carburetors get hot after the



Piston being lifted by a screwdriver



Thermal image looking down the barrel

engine has been stopped is not because of their proximity to the inlet manifold but because of the hot gases 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 gases to be vented and cold gases 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 where there may be other sources of heat. For anybody wishing to investigate potential solutions, an infrared thermometer or, better still, a thermal imaging camera is the ideal way to identify hot spots. However, remember that as soon as you open the bonnet, the temperature profile will change. As an alternative, digital multimeters 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. This article suggests a number of ways to mitigate these problems but, other than changing to a fuel with a lower percentage of front end components, there is probably no magic solution.

I am fortunate: 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. ●

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FUEL NEWS: Manchester XPAG Tests, Modern Petrol – Volatility

✦ Paul Ireland

The Federation of British Historic Vehicle clubs contributed some financial support to this series of tests in 2016. Paul Ireland has kindly written a summary of his findings for the FBHVC Newsletter, reproduced here.

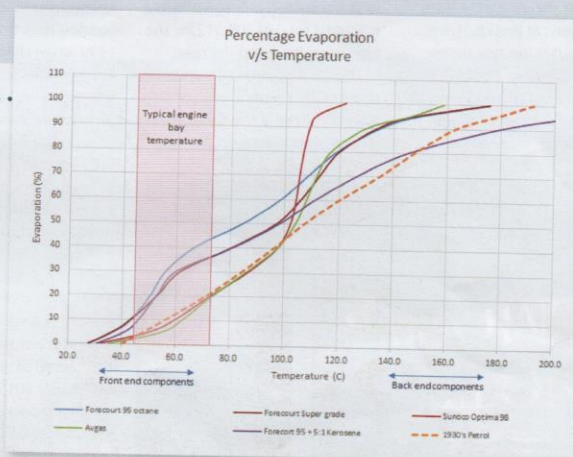
INTRODUCTION

To investigate the problems of running classic cars on modern petrol, a series of tests has been run on a 1940s twin SU carburettor XPAG engine at Manchester University School of Mechanical, Aerospace and Civil Engineering.

Petrol consists of over 300 different hydrocarbons. Measuring the volume of

fuel that evaporates as a sample of petrol is heated gives a distillation curve for that fuel. The graph above compares the distillation

curves of the different fuels used in the Manchester tests and that of 1930s petrol which remained virtually unchanged.



The curve for modern 95 octane forecourt petrol (blue line) compared to 1930s petrol (the orange dotted line) shows that classic petrol is much less volatile, especially at typical engine bay temperatures. This increased volatility of modern petrol is at the heart of the problems suffered by classic car owners.

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, most of which goes into heating the engine bay.

At Manchester, the highest petrol temperature in the carburettors when running at full power was 420°C. Not sufficiently high to cause problems.

The thermal image shows the blue float chambers silhouetted against the white (3000°C plus) exhaust manifold. Despite being positioned less than one inch above the exhaust manifold, the petrol flowing through the carburettors is keeping them cool. After the engine was stopped, the tests showed the carburettors were being heated by hot gasses coming from the engine through the inlet manifold, not by heat from the exhaust manifold: thus demonstrating that it is not obvious how the carburettors are being heated.

In slow moving traffic, two effects work to increase under-bonnet and petrol temperatures. Although the engine is running at low power and producing less heat, the rate at which heat is lost is reduced, there is less air flow through the engine bay. 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 fuel (above) shows a rapid rise in the volume of fuel evaporating between 450°C and 700°C. As the fuel boils, vapour bubbles in the petrol result in the carburettor delivering a much weaker mixture. This is what causes the

engine to stop or prevents it from restarting.

The best way to address this problem is to use a petrol with fewer low temperature components, more like the 1930s petrol. This reduces the volume of fuel that will boil as the engine bay gets hotter.

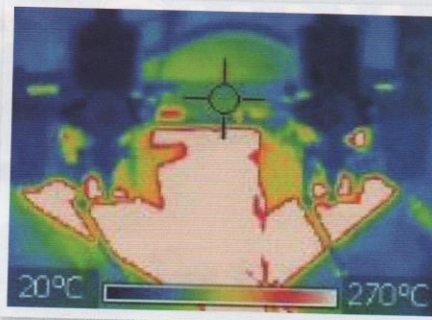
Unfortunately, it is not possible to make any specific recommendations for two reasons. Firstly, the regional UK fuel distribution industry is served by around 14 different refineries, all of which produce slightly different base stock. Secondly, there are three different grades of fuel are sold throughout the year:

- Winter fuel - October to April.
- Intermediate fuel - April to May and September to October.
- Summer fuel - June to August. This will probably have fewer low temperature components.

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 petrol is being sold.

The data above indicates super grade fuels are possibly less volatile. However, it is worth trying different brands to find out which petrol and grade gives the smoothest performance and will reduce vaporisation problems.

It is important the engine is properly tuned. Even a few percent reduction in efficiency, probably not noticeable in normal road use, will increase the amount of waste heat. The cooling system should also be working efficiently. Electric radiator fans help keep air circulating but may make matters worse. In slow moving traffic, they are drawing hot air through the radiator and blowing it into the engine bay. It is also worth fitting a timer or equivalent circuit to ensure any electric



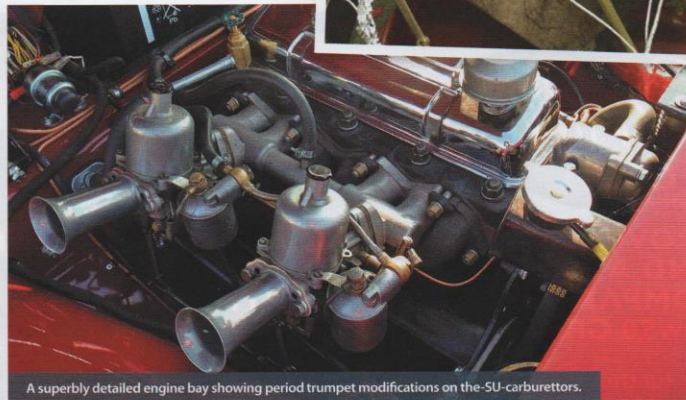
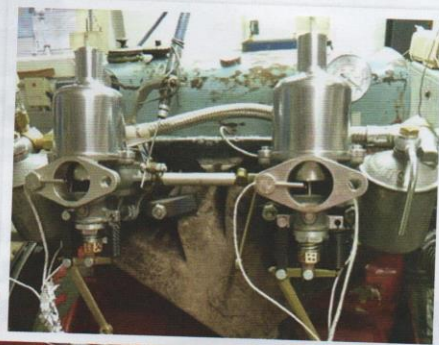
Heat map.

fans continue to run for around 5-10 minutes after the engine has stopped.

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 low temperature volatility of petrol. An infrared thermometer or thermal imaging camera is the ideal way to identify hot spots. Unfortunately, as soon the bonnet is opened, the temperature profile will change. As an alternative, digital multi-meters with thermocouples are now inexpensive and provide the means to allow your passenger to accurately measure the temperature of the fuel system even while a car is moving.

Unfortunately, there is no magic solution to this problem but with care it is possible to reduce its severity.

SU carbs on test.



A superbly detailed engine bay showing period trumpet modifications on the SU carburettors.