Investigating the effect of ethanol concentration in petrol on carburettor components

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Abstract

Up until the late 1980s, the majority of cars used carburetors as their fueling system, as opposed to the electronic fuel injection fitted to cars today. Since the development of such vehicles, petrol composition has changed dramatically, most notably with the removal of Tetraethyl Lead and addition of ethanol. Historic concerns about ethanol in fuel among the classic car community due to its supposed effects on the degradation of carburetor components, amongst other issues, has led to the proposal by the UK government proposing the introduction of a standard of 10% ethanol in petroleum from 2016 has being met with some concern. This study aimed to test the effect of ethanol in fuel on the degradation of two carburetor components, rubber 'o' rings which act as seals from float chamber to jet and brass jet material, indicative in the design of most carburetors. Components were immersed in a variety of solutions, which aimed to be able to discriminate between the effect of ethanol concentration and the combined effect of ethanol in fuel, and modern vs original type 4* fuel, for a period of 11 weeks. After the immersion period elapsed, a variety of analyses techniques were used to determine if there was a difference between these solutions in the degradation of components within them, and if so where these differences lay. It was shown that there was no significant difference between treatments on brass jet components, but that the breaking strains of rubber 'o' rings showed significant differences. These differences showed no significant effect between the current 5% ethanol and proposed 10%, however did show differences on concentrations above 10%. The methodology here, however, could have been improved upon vastly, and recommendations are made for data loggers and automated stress analysis, as well as durometer testing to be used in a repeat of this investigation, which should use a longer immersion period in order to better demonstrate differences between treatments.

Introduction

Fuel development in the UK and overseas is constantly ongoing, with one of the biggest changes in recent times being the abolition of the use of lead in petrol from the year 2000 (Butkusa & Pukalskasb, 2004), due to environmental concerns (Hepple, 1972), and the subsequent introduction of ethanol.

Lead was originally added to fuel in the form of Tetraethyl Lead (TEL) to increase the octane of the fuel as well as to act as an anti-knocking agent, preventing pre-ignition (also known, onomatopoeically, as 'pinking') of the fuel in the cylinders due to compression (as in a diesel engine) as opposed to igniting with the timed spark provided from the distributor via the spark plugs. It also coated the valve surfaces (G&S Valves, 2010) in the engine cylinder head in a thin layer of TEL, acting as a lubricant and sacrificial barrier, reducing wear of valve seats. During the 1970s, health concerns over the use of lead in petrol (Hepple, 1972) lead to the beginning of its use being phased out, finally being removed from general sale completely from the year 2000 (Butkusa & Pukalskasb, 2004).

Implications to health of lead in the environment, and consequently taken into the blood of the population, can be severe; particularly in young children (Tong, et al., 2000). As such, urban air quality legislation has been put in place, part of which led to the removal of TEL from fuel completely in 2000. Catalytic converters on petrol vehicles and particle traps on diesels are also used on modern vehicles to reduce emissions in line with this legislation, and emissions tests became part of the MOT

roadworthiness test for vehicles produced after 1975, with visual checks for those produced before this date (VOSA, 2014). 'Grandfathers rights' apply to any vehicle tested under this system, meaning that it only needs meet the emissions requirements in place at the time of manufacture.

It was found that ethanol, when added to petrol, increased the octane in a similar manor to TEL and also had anti-knocking properties. The sustainable nature of the ethanol (sustainable in the fact that it is not a fossil fuel, however debatably sustainable politically in terms of land usage, particularly in Brazil (Smith, 2010), with concerns that more financially valuable sugar cane will be grown on land which has previously been used for food production which, when 35% of the country's population live in poverty (IFAD, 2010), there are significant political implications about its use.) means that it is favoured by legislative powers, meaning that pump fuel in the UK is allowed to contain up to 5% ethanol to 95% petrol, E5, which the majority of pump fuels do. It has been proposed by the UK government (Owen, 2013) that by 2016, the standard will become E10 (90% petrol : 10% ethanol).

Concerns have arisen among the classic car fraternity that introducing such a high concentration of ethanol into fuels, which the cars were not designed for, could have a detrimental effect on the degradation of key components. This is of particular concern to the Federation of British Historic Vehicle Clubs due to the potential financial implications for owners and the possibility of vehicles of member clubs being unable to be used 'without restriction or modification' on Britain's roads. Manufacturers of modern cars design out potential for damage by ethanol from their cars and carry out research into the effects of different fuel types on their vehicles as part of their ongoing testing processes, however those cars no longer in production are not part of this. Some compatibility issues of materials with respect to ethanol has come to light through this research, including early degradation of rubber, brass and cork (used in some older carburettor systems) materials when exposed to ethanol based fuel, including E85 (Advanced Motor Fuels, 2013). Research has also beencarried out into the effect of ethanol based fuels on the valve surfaces of older engines (Vintage Sports Car Club, 1998), and the effectiveness of TEL additives on the market at avoiding damage to these surfaces (Federation of British Historic Vehicle Clubs, 1999)

This investigation into the effect of these changes in fuel composition and proposed future changes on carburettor (fuelling) components of older vehicles has implications in several areas and, thus, must draw from each of these. The introduction of E10 petrol in Europe, and the proposed introduction of this as a baseline in the UK have sparked a great deal of discussion and concern from many in the Classic Car movement, where carburettors are used. It should be noted, however, that carburettors containing similar components to those studied in this investigation, remained in usage until 1994 (Rockauto.com., 2010). The Federation of British Historic Vehicle Clubs exists to "maintain our freedom to use yesterday's vehicles on tomorrows roads" "without need for modification" (Federation of British Historic Vehicle Clubs, 2014) and hence there is concern about legislation being put in place to allow fuels unsuitable for yesterday's vehicles to become the only fuel widely available and thus restrict the use of these vehicles.

Older vehicles, including those designed to run on leaded petrol without ethanol, use Carburettors to distributor the fuel into the cylinders of the engine for combustion. These carburettors consist of three key components: the cast (usually aluminium) body of the carburettor, the needle and jet assembly which acts to regulate the amount of fuel drawn into the inlet manifold for distribution to the cylinders and combustion dependent on the throttle position and current engine revolutions,

and the rubber seals which allow the carburettor to remain a safe, leak free, closed system – avoiding risk of fire caused by leaking petrol. Concerns have arisen through anecdotal evidence (Hannham, 2013) that ethanol based fuels can cause harm to each of these three main components as well as rubber fuel lines, rubber diaphragms in fuel pumps, and the hydroscopic nature of the ethanol causing rust in steel fuel tanks of vehicles which are not used regularly.

Although there has been widespread speculation on the damage to rubber, aluminium and brass components, research into this area has been widely neglected in relation to classic cars. The main area of analysis until now, based on research that has been carried out thus far in relation to classic cars specifically, has been on valve seat wear/valve recession in the cylinder heads (Butkusa & Pukalskasb, 2004) (Vintage Sports Car Club, 1998) and the effectiveness of various lead additives on the market on preventing this (Federation of British Historic Vehicle Clubs, 1999) (Federation of British Historic Vehicle Clubs, 2014).

This valve seat recession is indicative of cars designed for the use of leaded petrol, which burns cooler than modern ethanol based fuel, and coats the valves in TEL adding a layer of protection to them, being run of E5. Although there are additives available to help prevent this, who's effectiveness was evaluated by the FBHVC (Federation of British Historic Vehicle Clubs, 1999), it is the view of many classic car owners that these additives are not worth the cost, and re-engineering the engine and inserting hardened valve seats and hardened valves (G&S Valves, 2010), as fitted to modern engines, is the best course of action. This, however, negates the FBHVC mission statement of vehicles being able to be used "without modification".

Cast aluminium component degradation with exposure to ethanol-based fuels has been observed (Wirot, et al., 2012). When using different concentrations of ethanol in fuel, all instances showed greater corrosion as shown by weight loss. It was also observed that those components exposed to higher concentrations of ethanol suffered greater degradation of surface structure and consequently weight loss, as hypothesised for the brass components in this investigation. This investigation also looks into measuring depths of pits using a scanning electron microscope, as well as weight loss over time, and my analysis of their data shows that the pit depth is proportional to weight loss.

The components studies in this investigation are rubber 'o' rings and the effect of exposure to different fuel types on their breaking strain and stretch under an arbitrary 1kg load. Brass components which are indicative of the jet and needle components, which regulate mixture and fuelling with changes in throttle position, will be analysed for weight loss caused by immersion in the varying solutions. The implication of degrading rubber 'o' rings is that a degraded 'o' ring could lead to fuel leakage and the possibility of fire. In relation to the brass components, David Vizard talks, in his book 'Tuning the A series engine' which is widely accepted to be the absolute authority on this engine type but has implications across the board for carburetted engines, about the issue of Jet and needle wear in the carburettor – in this instance in reference to the use of bias needles, although the principle still stands for any potential dissolution by ethanol in the fuel – on mixture maintenance (and therefore 'clean' running) (Vizard, 1999). Having established that weight loss is proportional to change in surface structure (Wirot, et al., 2012), if ethanol-based fuel is shown to cause weight loss

on the brass jet components analysed, it can be seen that the air/fuel mixture of the carburettor would be compromised, reducing engine efficiency.

A previous study of biofuels and their effect of PVC/NBR blend rubbers, (Maciel, et al., 2011), investigated the effect of temperature on the blends as well as different fuels and found that at the highest temperature studied there was the greatest change in physical composition and properties of the PVC/NBR blend rubbers, as well as the biggest change being when exposed to ethanol fuel. This study was carried out in Brazil, where ethanol-based fuels have been far more widely used than in the UK, and flex-fuel cars (which can run from petrol, ethanol or any combination thereof using fuel injection and monitoring to supply the correct amounts of the current mix of fuels to the pistons) are popular. This experiment uses similar immersion techniques to those used throughout the investigation in this document, but runs 20, 30 and 60 day trials, and concludes that degradation increases with time.

To conclude, there has already been some research into the effect of more modern fuels on older vehicles, with one of the key studies being into valve seat recession and the prevention thereof with additives. Other investigation, both in this context and beyond note material degradation when exposed to ethanol, with anecdotal evidence of degradation being reported through the classic car press and discussion forums. As such, the study carried out for this project, looking specifically at two of the components that the anecdotal evidence notes, which are also key components for two different types of failure (unclean running caused by jet or needle wear and leaking and potential for fire from rubber degradation) make this a worthwhile study to carry out.

Aims

This investigation will look at the effect of ethanol, and also that of an increased concentration thereof, on carburettor components, using the HS2 type SU carburettor which was fitted to many British cars and whose components, and materials thereof, are representative of those used in most carburetted vehicles as a case-study. Key areas of the carburettor which will be focussed on are the rubber 'o'-rings which seal the jet to the float chamber of the carburettor and the jets which work with needles of the same material to provide a precise mixture of fuel and air to the engine, as shown in figure 1.

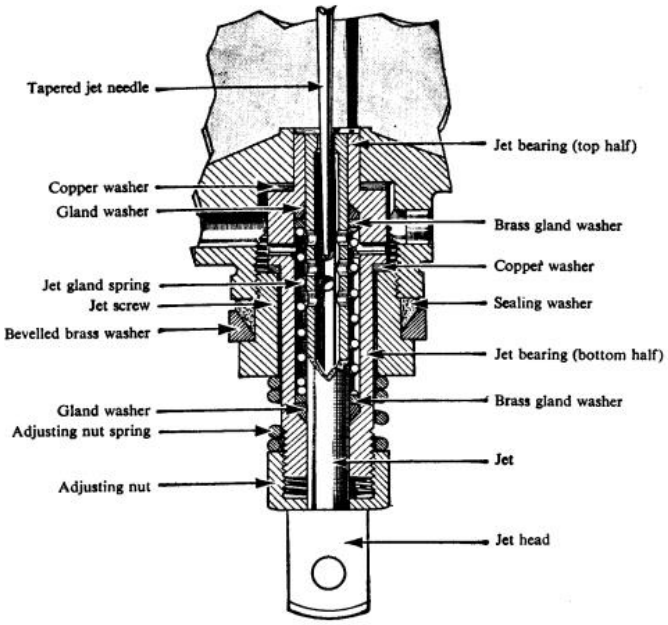

Fig. B.17
An enlarged view of the jet assembly, showing its component parts

Figure 1: The Jet of an HS2 SU Carburettor (British Motor Corperation, 1965)

Degradation of the rubber 'o' rings could potentially lead to a fuel leak and fire and, therefore, structure of these will be studied. Any erosion of the jet material would result in a change in the fuelling of the vehicle and, therefore, the emissions produced; as such, the rate of erosion of jet material will also be studied.

This investigation aims to analyse any difference in this degradation or erosion when exposed to solutions of differing ethanol concentrations, simulating current E5; proposed E10; with other concentrations increasing up to E25 as currently used in Brazil. Taking into consideration other literature and views expressed by individuals I have spoken to prior to this investigation, the hypotheses of this experiment are that with increased concentration of ethanol, whether in solution with fuel or in solution with H_2O, degradation of rubber and brass components will increase.

Methods

There were two main elements to this investigation. Firstly, the analysis of rubber 'o' rings in relation to braking strain and stretch under an arbitrary 1kg load. Secondly, analysis of change in mass of brass jet components when exposed to solutions of varying ethanol concentration.

New components were used for this testing, which were donated for the investigation by Burlen fuel systems. All these components were requested to be supplied from the same batch of manufacture. It should be noted that these components are not necessarily completely indicative of original components fitted to vehicles, but starting from a datum where all the components are new is the only way to ensure a meaningful set of results can be collected. It is also worth noting that, although these components may not completely mimic the original components fitted to the vehicles from factory, the majority of vehicles still on the road will be using these replacement parts.

Preparing the solutions

For both analyses, 250ml volumetric flasks were used to mix and store solutions of varying concentrations, which were mixed up using standard methodology to the concentrations shown in table 1, below.

Table 1: Solution ID descriptions for mixing

Solution	Volume ethanol added (ml)	Solution ID
Deionised Water	0	1
5% ethanol + H_20	12.5	2
10% ethanol + H_20	25	3
15% ethanol + H_20	37.5	4
20% ethanol + H_20	50	5
25% ethanol + H_20	62.5	6
100% ethanol	250	7
4* pump petrol	0	8
4* pump petrol + 5% ethanol	12.5	9
4* pump petrol + 10% ethanol	25	10
Pump unleaded	0	11
French pump E10	0	12

One of the key issues with the solutions required was sourcing the 4* and E10 fuels. The 4* was sourced from an FBHVC (Federation of British Historic Vehicle Clubs) - approved filling station in Buckingham. The E10 fuel was sourced in France, at a Shell filling station, as this is a fuel composition indicative of that proposed to be introduced to the UK market. Pump unleaded was easier to source, and was collected from the local Shell garage in Headington.

Appropriately sized measuring cylinders were used to measure the ethanol to be added to each solution, which was then decanted into the volumetric flasks which were topped up with either deionised water or 4* petrol as appropriate.

A fume cupboard was used throughout the process of mixing the solutions, and continued to be used throughout the duration of the investigation.

Preparing the Brass components

For the part of the investigation testing the effect of each of the solutions on mass changes of brass components, Jet tubes from the carburettor were used as the analysed component. Fifteen of these jet tubes were acquired from Burlen fuel systems, and were machined to make 30 identical components to test.

First, each of the fifteen jet tubes were 'faced-off' on a Myford model-makers lathe, as shown in figure 2, removing the narrow end which, in service, provides the tolerance fit between jet and needle.

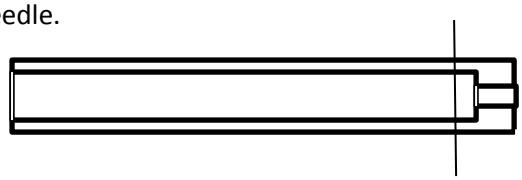

Figure 2: Diagram showing cross section of the jet tube component, with line denoting point to which the jet was 'faced-off'

Once the tubes were all 'faced-off' to a uniform length (to a tolerance, using an imperial measure, of 2-thousanths of an inch (equivalent to 0.0508mm), as measured with an inch-to-two-inch micrometer) and internal diameter, the lathe was then used to de-bur the machined end inside and out.

The overall length of each component was then taken again using the micrometer, this length then divided by 2, then half the width of the lathe's paring tool added to the figure. A depth micrometer was then used to position the component in the chuck of the lathe at this distance from the paring tool, so that the tool would exactly halve the component. This attention to detail is to ensure that each component has a comparable surface area to volume ratio, removing a potential source of error and improving the potential validity of results.

The resultant 30 components were then de-burred, as before, at the machined faces. A mitre block was then used to steady each component, while a three sided file was drawn across them to scribe tally marks – 'I,II,III' – to the tubes, denoting a 'set of three replicates, and making them identifiable within their solution sets throughout the investigation.

Brass component testing for mass change

First, each of the sets of jet tubes were assigned a solution to be immersed in. the solution IDs studied with regard to the brass components, from Table 1, were 1,2,3,6,7,8,9,10,11,12. This allows a good range of ethanol concentration to be studdied, while allowing 3 replicates to be used for each solution, considering the available number of components for testing. Once assigned to these solutions, each set was weighed using the 4-point balance in the geology department, as it was mounted on granite and recently calibrated (and would not be re-calibrated before the end of the trial period). Before weighing, each of the tubes was cleaned with a lint-free cloth, and the balance doors closed and the reading on the balance allowed to stabilise before a figure was recorded. The initial masses recorded are available in the appendices.

Once weighed, the tubes were carefully placed into their respective plastic containers, being slid down the side to avoid abrasion. The appropriate solutions were then added in excess to the containers and the lids screwed on tightly. The containers were then placed on the orbital shaker and left for 11 weeks for any change to occur.

After the 11 weeks immersion period, the components were removed from their containers, rinsed with their respective solutions, before being placed in a drying oven for 10 minutes, dried with a lint-free cloth and masses taken as outlined above.

Unfortunately, solutions 8-11 had evaporated to almost completely dry over this period, and therefore the mass taken at the second weighing was regarded as a new 'start' mass, and the experiment re-run for a further 11 weeks for these components, with glass bottles with ground glass stoppers being used as the containment vessels, and Parafilm being used as secondary protection from evaporation. After these 11 weeks, the second weighing was repeated.

For both investigations, within the fume cupboard, an orbital shaker was set up on which the trial solutions were placed throughout the investigation, breaking down any local concentration gradients.

Analysis of rubber components

Rubber components were treated in the same way as the brass components, in the fact that they were immersed for the same period of time in the same types of bottle on the orbital shaker, but in this case 5 replicates were used in each solution and each of the 12 solutions, shown in table 1, were used. The same issue arose with evaporation that arose with the brass components and replacement 'o' rings were sourced from the same batch and repeated. Only three o rings were able to be sourced for each replicate for solutions 8-12. This is important to note, as it lead to a necessity to modify the Tukey test used for analysis, which is described later.

Once the immersion process had been carried out, for the allotted 11 weeks, the length of stretch under a '1kg' load, and breaking strain an of the 'o' rings was analysed. For each of the five replicates in each treatment, a two loops of string were tied through the 'o' ring. The top loop was attached to a clamp-stand, which was anchored with house-bricks covered in cork mats, as shown in figure 3, and gradually increasing mass added to the bottom loop by means of a set of standard weights.

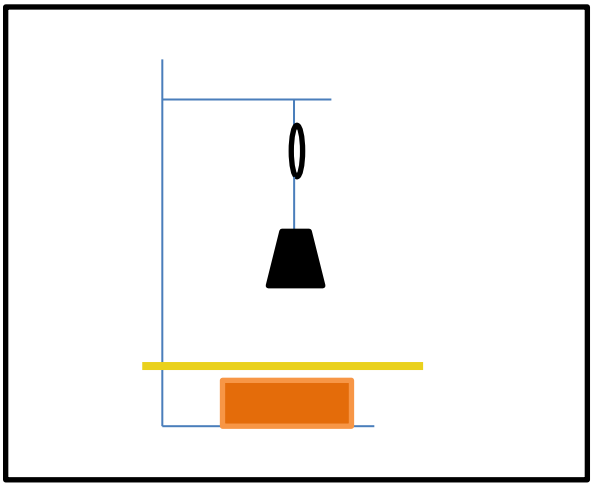

Figure 3: Apparatus for measuring breaking strain

To ensure that the correct breaking strain was recorded, 10 second was left between each increase in mass, and masses were changed with each addition to ensure a progressive addition of approximately 5g at a time. The addition of mass continued to be added until the 'o' ring broke. Note, the standard masses were not exactly the mass stamped on them, so final mass was measured on a fine balance. The final mass added was then recorded for each.

Results

Once the experiment had run for the allotted time period, noting the necessity to re-run part of the experiment due to evaporation of solutions, and the brass ad rubber analyses had been carried out as described, data was collected and tabulated (available in the appendices section of this document).

Brass analyses

It should be noted that the brass components in treatment 1 were omitted from the analysis, due to the fact that small fragments of brass ('swarf' from the machining process) were found in the bottom of the solution, and therefore it is not possible to determine which of the replicates they came from.

A two factor analysis of variants with replication was taken for the data collected, which produced a 'P' value of 0.991478 – considerably greater than the 0.05 threshold for a significant result, meaning that the Null hypothesis for this particular part of the experiment is overwhelmingly upheld. There is insignificant variation either between treatments or between replicates to show that ethanol or fuel concentration has any significant effect on mass change in the brass components within the carburettor under these laboratory conditions. As such, it can be considered that ethanol in fuel, in any concentration, is of no significant threat to the wear of brass carburettor components.

Rubber analysis

Braking strain

A single factor analysis of variants produces a P value of 6.21×10^{-17}, again showing a significant difference.

A Tukey test was then carried out to determine differences between variables. This was a modified Tukey test due to the fact that the dataset contained unequal replicates between treatments, a consequence of the need to repeat the immersion in solutions 8-12, as detailed in the methods section of this document. As such, it was advised that the denominator in the equation of the tukey test (relating to the number of replicates) was modified as shown in table 2, below.

Table 2: Modification of denominator for Tukey Test of braking strain in relation to number of replicates across matrix

where comparing 5 vs 5 = denominator = 5	467.6309
where comparing 3 vs 3 = denominator = 3	603.7089
where comparing 5 vs 3 = denominator = 4	522.8272

The results of the Tukey test are shown in figure 4 below.

	1	2	3	4	5	6	7	8	9	10	11	12
1	x											
2	56.492	x										
3	321.642	265.15	x					red is significant				
4	453.972	397.48	132.33	x				green is insignificant				
5	479.984	423.492	158.342	26.012	x							
6	653.012	596.52	331.37	199.04	173.028	x						
7	895.316	838.824	573.674	441.344	415.332	242.304	x					
8	1294.168	1237.676	972.526	840.196	814.184	641.156	398.852	x				
9	1629.251	1572.759	1307.609	1175.279	1149.267	976.2393	733.9353	335.0833	x			
10	1760.105	1703.613	1438.463	1306.133	1280.121	1107.093	864.7887	465.9367	130.8533	x		
11	1646.088	1589.596	1324.446	1192.116	1166.104	993.076	750.772	351.92	16.83667	-114.017	x	
12	1702.081	1645.589	1380.439	1248.109	1222.097	1049.069	806.7653	407.9133	72.83	-58.0233	55.99333	x

Figure 4: Shaded matrix of results of Tukey test demonstrating where significance lies between treatments. Numbers on axis refer to solution IDs outlined in table 1.

Due to the potential uncertainty of the tukey test because of the difference in number of replicates, T tests were then carried out between each set of treatments and the significance plotted in a matrix, as shown in figure 5 below:

Figure 5: Significance according to 2 tailed T test. Numbers on axis refer to solution IDs outlined in table 1.

As can be seen by comparing figures 4 and 5, the two methods of data analysis do not completely correspond, however there are some clear similarities.

Stretch under 1kg load

A single factor analysis of variants shows a P value of 0.018123, showing a significant difference. A modified tukey test, as described in the previous section (with numbers used for analysis being shown in Table 3), was then used to show where these differences were present. This is presented in figure 5 below.

Table 3: Modification of denominator for Tukey Test of stretch under 1kg load in relation to number of replicates across matrix

where comparing 5 vs 5 = denominator = 5	0.716837
where comparing 3 vs 3 = denominator = 3	0.925432
where comparing 5 vs 3 = denominator = 4	0.801448

	1	2	3	4	5	6	7	8	9	10	11	12
1	x											
2	0.4	x										
3	0	-0.4	x					red is significant				
4	-0.4	-0.8	-0.4	x				green is insignificant				
5	-0.3	-0.7	-0.3	0.1	x							
6	-0.1	-0.5	-0.1	0.3	0.2	x						
7	-0.1	-0.5	-0.1	0.3	0.2	0	x					
8	0.033333	-0.36667	0.033333	0.433333	0.333333	0.133333	0.133333	x				
9	-0.46667	-0.86667	-0.46667	-0.06667	-0.16667	-0.36667	-0.36667	-0.5	x			
10	-0.13333	-0.53333	-0.13333	0.266667	0.166667	-0.03333	-0.03333	-0.16667	0.333333	x		
11	0.033333	-0.36667	0.033333	0.433333	0.333333	0.133333	0.133333	0	0.5	0.166667	x	
12	-0.46667	-0.86667	-0.46667	-0.06667	-0.16667	-0.36667	-0.36667	-0.5	0	-0.33333	-0.5	x

Figure 6: Shaded results of Tukey test for stretch under 1kg load showing which treatments significance lies between. Numbers on axis refer to solution IDs outlined in table 1.

Figure 6 shows three points of significance between solution 2, 5% ethanol with H_2O, and solution 4, 15% ethanol with H_2O; solution 9, 5% ethanol with 4*; and solution 12, E10.

Discussion

Before coming to any conclusions, we must first consider that this experiment employed basic methodology, and used resources and time periods available to ascertain whether the different concentrations of ethanol in both water and petrol had significant effects on the degradation of the carburettor components studied. Further work should be carried out to confirm the findings of this experiment, over longer time periods and with modified testing methods for the rubber analysis.

It should also be noted that the components tested were modern replacement units, so as to be able to start from a datum – as no new old stock items were available for this testing. It might be considered that earlier components, such as those fitted to the cars from factory or as replacements in period, may experience different effects. Considering the lack of data for the older components, and reported issues associated with fuel component degradation which triggered this investigation, owners would be advised to replace original fuel-system components with remanufactured components such as those from Burlen Fuel Systems studied in this project. With such critical components for the safe and efficient operation of older vehicles, further research needs to be carried out before confidence in older components can be given.

Brass mass change

The ‘p’ value of 0.991478 for variation within the brass component experiment for change in mass overwhelmingly upholds the null hypothesis under these conditions. From this, it can be concluded that there is no significant effect of ethanol in fuel on the degradation of the brass jet, and by extension, needle components. Therefore the initial hypothesis that the introduction of higher concentrations of ethanol in fuel will affect the ability to retain a set mixture adjustment due to chemical degradation of these brass regulatory components, as has been muted by several individuals I have spoken to regarding this issue, can be rejected.

Braking strain of rubber

The key comparisons that must be drawn from this dataset to analyse the hypothesis that degradation of the rubber component (as demonstrated by a reduced breaking strain) is relative to higher the ethanol concentration in fuel are those that would show a conclusive relationship between the presence or otherwise of ethanol in the solution, for example solutions 1vs7 and 7vs8 (see Table 1, repeated below for ease of reference)

Table 4: Solution ID descriptions

Solution	Volume ethanol added (ml)	Solution ID
Deionised Water	0	1
5% ethanol + H_20	12.5	2
10% ethanol + H_20	25	3
15% ethanol + H_20	37.5	4
20% ethanol + H_20	50	5
25% ethanol + H_20	62.5	6
100% ethanol	250	7
4* pump petrol	0	8
4* pump petrol + 5% ethanol	12.5	9
4* pump petrol + 10% ethanol	25	10
Pump unleaded	0	11
French pump E10	0	12

Although both figures 4 and 5 show significance between solutions 1 and 7 (deionised water vs 100% ethanol), as would be expected, both matrices show insignificant relationships between 7 and 8 (100% ethanol vs 4* petrol). From this, it could be said that it is a combination of ethanol and petrol that causes the reported degradation of the rubber components. It is worth, therefore, considering the relationship of braking strains between solutions 8,9 and 10. Again, figures 4 and 5 correspond in showing no significant differences between these areas.

Further comparisons can be drawn between higher concentrations of ethanol than the 10% used in solution 10. When solutions 2-6 were compared, significant differences were shown in figure 5 for 2,4,5&6 in relation to 2, with 3 being only moderately significant, whereas the modified tukey test matrix in figure 4 shows only significance between 2 and 6. Solution 3 is shown by figure 5 to be moderately significantly different from solution 6, with no significant differences shown in figure 4. Solution 4 was shown by both figures 4 and 5 to have insignificant difference to 5 and 6, as was solution 5 to 6. This shows that there is a significant increase in the degradation of the rubber ‘o’ ring components tested above a concentration of 10%. With this observed trend in degradation over a short period or immersion, it could be considered that over a longer period of immersion greater differences would occur, possibly resulting in the linear trend in relation to ethanol concentration originally hypothesised. What is shown from the data collected, however, that there is insignificant difference between the current 5% and proposed 10% ethanol concentrations under these conditions and, therefore, the null hypothesis is upheld.

It can be hypothesised that, if it is ethanol alone that is causing differing breaking strains of the rubber o rings that there will be no significant difference between solutions , 10 and 12, all of which contain 10% ethanol. Both figures 4 and 5, however, disprove this.

Stretch of rubber under 1kg

The error margin through parallax error on such a small measurement for this dataset, the lack of coloration, as would be expected, with the data collected for breaking strain, and with the the closeness of each of the 'significant' points to the modified tukey figures, mean that no meaningful conclusions can be drawn from this dataset. This could br improved upon, as described above, by using more high-tech and precise equipment, such as that shown in figure 7, to measure the degradation of the component.

Recommended improvements to methodology

It can be seen that there is some unreliability in this data, though the analysis of the ethanol in water solutions on their own stand to offer some meaningful conclusions. The rubber analysis methods in this experiment were, however, rather crude, and had a large margin of error (+- 5g). If this experiment were repeated, I would recommend that analysis of the hardness of the rubber 'o' rings could be carried out using a durometer hardness tester and breaking strain and durability testing to be carried out on a second set of replicates using an 'Admet eXpert 4000' (Schausohn, 2015), as shown in figure 7, or similar linked to a data logger to test durability and breaking strain with greater precision and within solution.

Figure 7: Admet eXpert 4000 with solution bath, recommended for durability testing of rubber components if experiment were to be repeated

Larger numbers of replicate, and the same number of replicates for each treatment would allow for greater accuracy and ease of data analysis, along with a longer time period for immersion would also be beneficial to better understanding the effect of ethanol on rubber degradation.

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Appendices

Bottle ID	Replicate ID	Initial Mass (g) 01/07/14	Mass (g) 15/09/14	Mass (g) 16/12/14	Change in mass (g)	Mean change in mass (g)	mean initial mass (g)
1	1	3.613	3.6053	Total with debris	-0.0076	-0.0005	3.5919
Debris Discovered at end of test:			0.0081	3.6206			
Debris Discovered at end of test:			0.0072				
1	2	3.5792	3.5798		-0.0006		
1	3	3.576	3.5693		0.0067		
2	1	3.6417	3.6419		-0.0002	-0.0003	3.6169
2	2	3.5595	3.5596		-0.0001		
2	3	3.6496	3.6503		-0.0007		
3	1	3.6116	3.6118		-0.0002	-0.0001	3.6077
3	2	3.6102	3.6103		-0.0001		
3	3	3.6013	3.6012		0.0001		
6	1	3.5562	3.5566		-0.0004	0.0000	3.6024
6	2	3.6071	3.6073		-0.0002		
6	3	3.6438	3.6431		0.0007		
7	1	3.6504	3.6505		-0.0001	-0.0001	3.6081
7	2	3.5743	3.5745		-0.0002		
7	3	3.5995	3.5994		0.0001		
8	1	3.61	3.61	3.6097	-0.0003	-0.0001	3.5866
8	2	3.566	3.5655	3.5655	0.0000		
8	3	3.5846	3.5843	3.5843	0.0000		
9	1	3.5718	3.5732	3.5717	-0.0015	-0.0016	3.5810
9	2	3.5875	3.5895	3.5878	-0.0017		
9	3	3.579	3.5804	3.5788	-0.0016		
10	1	3.5627	3.5625	3.5628	0.0003	0.0002	3.5928
10	2	3.6413	3.6415	3.6417	0.0002		
10	3	3.5738	3.5745	3.5747	0.0002		
11	1	3.6154	3.6148	3.6148	0.0000	-0.0001	3.6094
11	2	3.6512	3.6514	3.6512	-0.0002		
11	3	3.5632	3.5621	3.5621	0.0000		
12	1	3.6196	3.5628	3.563	0.0002	0.0001	3.6092
12	2	3.5633	3.6192	3.6192	0.0000		
12	3	3.6459	3.6456	3.6458	0.0002		
		NB: relicates 8-12 were re-run, so initial mass is taken from 15/09/14					

Appendix 1: Raw data from brass analysis

Treatment	Initial Length (mm)	Length under "1kg" initial load (mm)	Stretch with 1kg load (mm)	Braking weight (g)	mean initial stret	mean braking weight	Treatment
1	7.5	11	3.5	4356.3	3.2	4434.798	1
1	7.5	10.5	3	4329.24			
1	7.5	10.5	3	4559.82			
1	7.5	11	3.5	4563.55			
1	7.5	10.5	3	4365.08			
2	7.5	10	2.5	4310.13	2.833333333	4378.306	2
2	7.5	10.5	3	4356.3			
2	7.5	10	2.5	4560.09			
2	7.5	10.5	3	4505.45			
2	7.5	10.5	3	4159.56			
3	7.5	10	2.5	4329.24	3.2	4113.156	3
3	7.5	11	3.5	4016.22			
3	7.5	11	3.5	3923.25			
3	7.5	10.5	3	4201.12			
3	7.5	11	3.5	4095.95			
4	7.5	10.5	3	4081.42	3.583333333	3980.826	4
4	7.5	11	3.5	3953.3			
4	7.5	11.5	4	3991.43			
4	7.5	11.5	4	3952.35			
4	7.5	11	3.5	3925.63			
5	7.5	11.5	4	4086.77	3.5	3954.814	5
5	7.5	11	3.5	4063.31			
5	7.5	11	3.5	4000.27			
5	7.5	11	3.5	3727.03			
5	7.5	10.5	3	3896.69			
6	7.5	11	3.5	3513.8	3.3	3781.786	6
6	7.5	11	3.5	3819.53			
6	7.5	10.5	3	3923.25			
6	7.5	11	3.5	3694.84			
6	7.5	10.5	3	3957.51			
7	7.5	11	3.5	3520.25	3.3	3539.482	7
7	7.5	11	3.5	3626.19			
7	7.5	11	3.5	3596.12			
7	7.5	10.5	3	3530.37			
7	7.5	10.5	3	3424.48			
8	7.5	10.5	3	3198.72	3.166666667	3140.63	8
8	7.5	11	3.5	3532.84			
8	7.5	10.5	3	2690.33			
9	7.5	11.5	4	2682.55	3.666666667	2805.546667	9
9	7.5	11	3.5	3041.02			
9	7.5	11	3.5	2693.07			
10	7.5	11	3.5	2541.04	3.333333333	2674.693333	10
10	7.5	10.5	3	3095.52			
10	7.5	11	3.5	2387.52			
11	7.5	10.5	3	2582.87	3.166666667	2788.71	11
11	7.5	10.5	3	3248.52			
11	7.5	11	3.5	2534.74			
12	7.5	11.5	4	2588.13	3.666666667	2732.716667	12
12	7.5	11	3.5	2548.15			
12	7.5	11	3.5	3061.87			
				error= +- 10g			

Appendix 2: Raw data from rubber analysis

	Before	After
2	3.6417	3.6419
2	3.5595	3.5596
2	3.6496	3.6503
3	3.6116	3.6118
3	3.6102	3.6103
3	3.6013	3.6012
6	3.5562	3.5566
6	3.6071	3.6073
6	3.6438	3.6431
7	3.6504	3.6505
7	3.5743	3.5745
7	3.5995	3.5994
8	3.61	3.6097
8	3.5655	3.5655
8	3.5843	3.5843
9	3.5732	3.5717
9	3.5895	3.5878
9	3.5804	3.5788
10	3.5625	3.5628
10	3.6415	3.6417
10	3.5745	3.5747
11	3.6148	3.6148
11	3.6514	3.6512
11	3.5621	3.5621
12	3.5628	3.563
12	3.6192	3.6192
12	3.6456	3.6458

Anova: Two-Factor With Replication

SUMMARY	Before	After	Total
2			
Count	3	3	6
Sum	10.8508	10.8518	21.7026
Average	3.616933	3.617267	3.6171
Variance	0.00249	0.002512	0.002001
3			
Count	3	3	6
Sum	10.8231	10.8233	21.6464
Average	3.6077	3.607767	3.607733
Variance	3.12E-05	3.29E-05	2.56E-05
6			
Count	3	3	6
Sum	10.8071	10.807	21.6141
Average	3.602367	3.602333	3.60235
Variance	0.001935	0.001889	0.00153
7			
Count	3	3	6
Sum	10.8242	10.8244	21.6486
Average	3.608067	3.608133	3.6081
Variance	0.001503	0.001501	0.001202
8			
Count	3	3	6
Sum	10.7598	10.7595	21.5193
Average	3.5866	3.5865	3.58655
Variance	0.000499	0.000492	0.000396
9			
Count	3	3	6
Sum	10.7431	10.7383	21.4814
Average	3.581033	3.579433	3.580233
Variance	6.67E-05	6.51E-05	5.35E-05
10			
Count	3	3	6
Sum	10.7785	10.7792	21.5577
Average	3.592833	3.593067	3.59295
Variance	0.001812	0.001809	0.001449
11			
Count	3	3	6
Sum	10.8283	10.8281	21.6564
Average	3.609433	3.609367	3.6094
Variance	0.002015	0.002007	0.001609
12			
Count	3	3	6
Sum	10.8276	10.828	21.6556
Average	3.6092	3.609333	3.609267
Variance	0.001789	0.001787	0.00143
Total			
Count	27	27	
Sum	97.2425	97.2396	
Average	3.601574	3.601467	
Variance	0.001068	0.001073	

ANOVA

Source of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0.007189	8	0.000899	0.667362	0.716356	2.208518
Columns	1.56E-07	1	1.56E-07	0.000116	0.991478	4.113165
Interactio	4E-06	8	4.99E-07	0.000371	1	2.208518
Within	0.048473	36	0.001346			
Total	0.055665	53				

Appendix 3: Anova statistical analysis for brass data

1	2	3	4	5	6	7	8	9	10	11	12
4356.3	4310.13	4329.24	4081.42	4086.77	3513.8	3520.25	3198.72	2682.55	2541.04	2582.87	2588.13
4329.24	4356.3	4016.22	3953.3	4063.31	3819.53	3626.19	3532.84	3041.02	3095.52	3248.52	2548.15
4559.82	4560.09	3923.25	3991.43	4000.27	3923.25	3596.12	2690.33	2693.07	2387.52	2534.74	3061.87
4563.55	4505.45	4201.12	3952.35	3727.03	3694.84	3530.37					
4365.08	4159.56	4095.95	3925.63	3896.69	3957.51	3424.48					

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	22173.99	4434.798	13593.15
Column 2	5	21891.53	4378.306	25548.27
Column 3	5	20565.78	4113.156	25046.72
Column 4	5	19904.13	3980.826	3711.69
Column 5	5	19774.07	3954.814	21628.49
Column 6	5	18908.93	3781.786	32922.93
Column 7	5	17697.41	3539.482	6101.125
Column 8	3	9421.89	3140.63	179986.6
Column 9	3	8416.64	2805.547	41613.44
Column 10	3	8024.08	2674.693	138713.4
Column 11	3	8366.13	2788.71	159148.1
Column 12	3	8198.15	2732.717	81656.04

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	18470782	11	1679162	37.17461	6.21E-17	2.051294
Within Gr	1716445	38	45169.59			
Total	20187226	49				

Appendix 4: Anova of rubber breaking strain

1	2	3	4	5	6	7	8	9	10	11	12
3.5	2.5	2.5	3	4	3.5	3.5	3	4	3.5	3	4
3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3	3	3.5
3	2.5	3.5	4	3.5	3	3.5	3	3.5	3.5	3.5	3.5
3.5	3	3	4	3.5	3.5	3					
3	3	3.5	3.5	3	3	3					

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	16	3.2	0.075
Column 2	5	14	2.8	0.075
Column 3	5	16	3.2	0.2
Column 4	5	18	3.6	0.175
Column 5	5	17.5	3.5	0.125
Column 6	5	16.5	3.3	0.075
Column 7	5	16.5	3.3	0.075
Column 8	3	9.5	3.166667	0.083333
Column 9	3	11	3.666667	0.083333
Column 1(	3	10	3.333333	0.083333
Column 1:	3	9.5	3.166667	0.083333
Column 12	3	11	3.666667	0.083333

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	2.911667	11	0.264697	2.493839	0.018123	2.051294
Within Gr(	4.033333	38	0.10614			
Total	6.945	49				

Appendix 5: Anova for stretch of rubber under 1kg load