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COMPARISON OF THE PERFORMANCE AND EMISSIONS OF A PETROL ENGINE USING A RANGE OF UNLEADED FUELS

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ABSTRACT

The use of fossil fuels for transportation purposes has increased significantly over the last 60 years, and the environmental effects of the use of fossil fuels have become a matter of concern in recent years. This has lead to the development of a number of fuels which are intended to reduce the environmental impact of the ever-growing use of motor vehicles. There are a number of views on the advantages and disadvantages of these fuels, such as dispute as to the life-cycle emissions and the impact on performance. It is the aim of this paper to present independent findings into the performance and emissions pros and cons for some alternative fuels, Regular Unleaded (91 octane), Premium Unleaded (95 octane) and Premium Unleaded, Ultimate (98 octane). In a full scale laboratory testing undertaken at Central Queensland University, it is found that Premium Unleaded and the Ultimate offer better power and torque efficiency with a grater percentage of specific fuel consumption compared to regular unleaded petrol. Moreover, the Ultimate appeared to have less exhaust emissions with lower concentration of all pollutants compared to regular unleaded petrol.

Keywords: *Unleaded Fuels, Petrol Engine, Emissions.*

1. INTRODUCTION

The term, greenhouse gas, refers to those gases which are believed to contribute to global warming through the greenhouse effect. This is due to the ability of these gases to absorb infrared radiation from the sun. Whilst they are all naturally occurring gases, the levels of a number of these gases in the atmosphere as a result of human activity are of concern within the global community. In recent years a great deal of concern has been raised regarding the apparent increase in global temperature, which is believed to be the result of an increase in the atmospheric concentration of a number of gases. These gases, termed greenhouse gases for the heating effect that they have on the Earth, include water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Water vapour, carbon dioxide and methane are products of the combustion process used in internal combustion engines. Water vapour causes the largest impact on global warming (between 36% and 66%) out of all of the greenhouse gases, however the concentration of water vapour in the atmosphere is not directly affected by human activity as it has a short lifespan in the atmosphere [1]. When addressing the issue of climate change and greenhouse gases, it is important to consider the impacts of human activity (anthropogenic impacts), as changes in human activity affect the levels of certain greenhouse gases. Carbon dioxide is the most prevalent of these greenhouse gases, making up approximately 72% of the total anthropogenic greenhouse gas emissions [2]. This equals approximately 25,028 million metric tonnes of carbon dioxide being released into the atmosphere each year, based on 2003 figures. Carbon dioxide emissions are responsible for between 9% and 26% of the total global warming impact [1]. Transportation emissions account for 14% of all greenhouse gas emissions, and 19.2% of carbon dioxide emissions [3]. This is a significant portion, and it has been suggested that by using alternative transport options, there will be a significant saving of greenhouse gas emissions.

There are a number of "alternative fuels" which are believed to be more environmentally friendly than fossil fuels. Some of these fuels are made from plant matter, which has the advantage of absorbing carbon dioxide while growing. One of these fuels is ethanol, whose use in the transportation sector is due to its ability to be mixed with standard petroleum based fuels such as petrol and gasoline, which reduces dependence on fossil fuels. As ethanol comes from a renewable source such as plant matter, emissions from its combustion are not considered to contribute to raising carbon dioxide stocks in the environment [4]. The burning of fossil fuels for transportation makes up approximately 14% of the global greenhouse gas emissions each year. In response to this, a number of options have been investigated as possible ways of reducing this impact on the environment. Such possibilities include electric vehicles, hydrogen fuelled vehicles, hybrid petrol/electric vehicles and fuels which are designed to produce less greenhouse gas emissions than regular fossil fuels. Petroleum products such as Premium Unleaded and unleaded petrol containing small amounts of ethanol are two examples of these claimed 'emission reducing' fuels. In Australia, the options for unleaded fuels include Unleaded (91 octane), Premium Unleaded (95 octane), a higher grade of premium unleaded (e.g. Ultimate from BP, 98 octane) and a mix of regular Unleaded petrol containing up to 10% ethanol which is commonly referred to as e10.

Bouris *et al.* [5] summarized the growing importance of understanding and controlling particulate emissions from gasoline engines and an experimental simulation approach was described with the potential for exploring particle deposition/capture and oxidation phenomena under well-controlled conditions. It was done by using artificially generated sub-100 nm carbon particles into a synthetic exhaust gas stream and by simulating engine-out soot emissions. Ochieng *et al.* [6] explained a vehicle performance and emission monitoring system and referred the procedures used to validate the data generated by both diesel and petrol powered vehicles. The system attains the specified performance levels for each of the subsystems, with aggregate mass emissions within 11.5%, 8.1% and 17.7% for CO, CO_2 and NO, respectively. Arapatsakos *et al.* [7] discussed the use of the fuels propane and butane-propane (80:20) in a four-stroke engine made to function with gasoline (petrol). It was observed that gas emissions were reduced compared with gasoline and the reduction for carbon monoxide emissions was found greater when butane-propane was used. Ristovski *et al.* [8] conducted a comparative study of the particle and carbon dioxide emissions from a fleet of six dedicated liquefied petroleum gas powered and five unleaded petrol powered new Ford Falcon Forte passenger vehicles at four different vehicle speeds—0 km/h, 40 km/h, 60 km/h, 80 km/h and 100 km/h. The study reported that the particle number emission factors ranged from 1011 to 1013 per km and was over 70% less with liquefied petroleum gas compared to unleaded petrol. Sayin *et al.* [9] studied the effect of using higher-octane gasoline (petrol) than that of engine requirement on the performance and exhaust emissions and showed that higher octane ratings than the requirement of an engine not only decreases engine performance but also increases exhaust emissions. Exhaust emissions from vehicles consist of a hot and complex mix of both gaseous CO_2) and particle phases range in size from 10 to 80 nm [9]. This study presents an experimental study to determine emissions and fuel consumption rates of petrol driven cars with some alternative unleaded fuels, Unleaded (91 octane), Premium Unleaded (95 octane) and Premium Unleaded, Ultimate (98 octane) available in Australian market.

2. METHODOLOGY

In order to understand the real world effects of using alternative fuels, several laboratory tests were conducted. By running an engine in the same situations using different fuels, it was anticipated that the differences between the fuels would be apparent. The test procedure was developed to enable the engine and exhaust characteristics to be investigated at a number of different engine speeds and air-fuel ratios. This procedure was developed specifically to suit the equipment available and the aims of this study.

2.1 Equipment

All of the equipment and software involved in the testing and data acquisition was supplied to Central Queensland University by Dyno Dynamics. The engine used in this study is a 2.4 litre four cylinder Toyota petrol engine (model 2AZ-FE) which is commonly found in modern Camry and Rav4 vehicles. The engine is in very good condition, having only been used occasionally for laboratory experiments and demonstrations. The dynamometer used is an engine type dynamometer, as opposed to the more commonly used chassis dynamometer. Its primary component is an electromagnet which applies a braking force to the engine drive shaft. This serves two purposes – to enable the calculation of the power and torque generated, and to control the engine speed as required by the test procedure.

The gas analyser used to analyse the exhaust gases is an Andros Model 6241A, and is capable of non-dispersive infrared as well as electrochemical analysis. This allows for the measurement of hydrocarbons (n-Hexane), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2) and NO_x (Nitric Oxide and Nitrogen Dioxide). It is important to note that the gas analyser detects a wide range of hydrocarbons, via a non-dispersive infrared sensor, and not just n-Hexane. While it is most effective at detecting n-Hexane due to its setup, it is compensated to give a good indication of the levels of other hydrocarbons.

2.2 Laboratory Process

The procedure was developed to test the performance and emissions of the engine at seven different speeds – 1200rpm, 1800rpm, 2400rpm, 3000rpm, 3600rpm, 4200rpm and 4800rpm. Each test run consisted of running the engine at a specified speed for 2 minutes to obtain stability in the performance and emission readings, and then recording the data 10 times within 20 seconds. The engine speed was then changed and the system allowed to stabilise and the test was repeated. This process was repeated until each of the 7 engine speeds has been tested 5 times. In order to minimize the effects of atmospheric variation throughout the testing, all experimental work was completed between the hours of 11am and 5pm. Testing was avoided on rainy days, and when the atmospheric conditions were considerably different from other test days.

2.3 Analysis Details

The data obtained was graphed with each characteristic plotted against the engine speed, or against air-fuel ratio or exhaust gas temperature where relevant. The graphical results clearly show the advantages and disadvantages of each fuel. For a large enough samples from a population, according to the Central Limit Theorem, the distribution of the sample mean is approximately normal, no matter what population it was drawn from [10]. The size of the sample required for this approximation to be valid is specified as greater than 30. As the test procedure in this study requires 50 samples of data to be taken for each point, it is possible to use this theorem. The Central Limit Theorem is important in analysing the results of this study, particularly the graphs produced. Since the sample of data taken approximately forms a normal distribution, 95.45% of sample values will lie within two standard deviations of the mean.

The Wilcoxon Rank-Sum Test is a statistical process that is used to determine whether two population means are statistically different. This is of importance in this study as the data is obtained from a laboratory situation with a number of inherent inaccuracies. The result of these inaccuracies is that some of the observed differences between the fuels are actually from experimental variation rather than the use of different fuels.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The comparison of power, torque and specific fuel consumptions are shown in Figures 1, 2, and 3 respectively. Each graph shows a comparison of the characteristics of the three fuels. It must be noted that the data used for Ultimate is based on 20 measurements, instead of 50 measurements as with the other fuels. This is due to complications with the throttle, and as a result, the variance of these values may be higher.

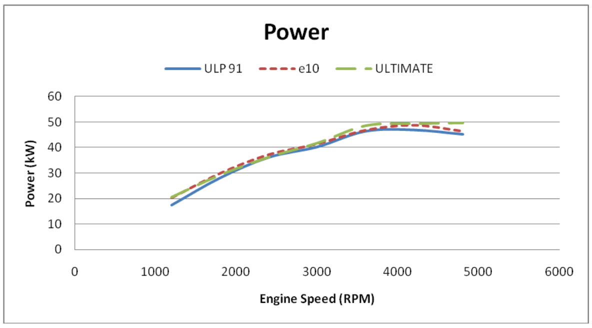

Figure 1: Comparison of engine brake power

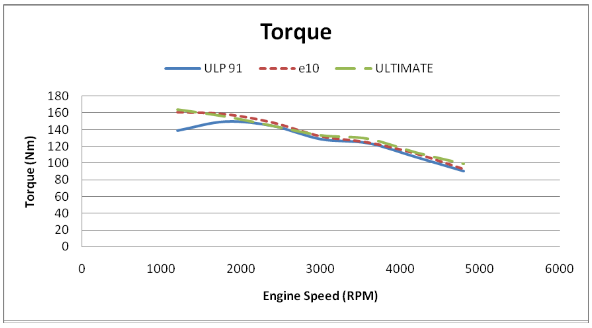

Figure 2: Comparison of engine brake torque

As shown in Figure 1, the power produced by the engine using each of the different fuels differed slightly. It appears at first glance that Ultimate produced slightly more power than the other fuels, however the complications experienced with the throttle during testing for Ultimate must be taken into consideration. The results of this study put the power of the engine approximately 5.07% higher than regular unleaded when using e10, and 6.7% higher than regular unleaded when the Ultimate is used. The peak power produced was 47kW, 48.9kW and 49.8kW for regular unleaded, e10 and Ultimate respectively. It was expected that the Ultimate would produce a higher power output, as its net calorific value is approximately 2.3% (by volume) higher than that of regular unleaded. The e10 fuel was expected to produce less power than regular unleaded fuel, due to its lower net calorific value. The 5.07% increase in power can possibly be explained by the extra oxygen content in the ethanol blend fuel causing the fuel to combust more completely. This explanation is supported by the fact that the carbon monoxide emissions are lower, and carbon dioxide emissions are higher when using e10. In Figure 2, the torque measurements vary with each different fuel by the same percentage as with the power measurements. This is expected as power is a function of torque. The maximum torque produced for regular unleaded was 149Nm, 161Nm for e10 and 164Nm for Ultimate. The specific fuel consumption (Figure 3) shows that per kilowatt-hour of energy produced, both e10 and Ultimate use less fuel (approximately 2.7% less for e10, and 1.6% less for Ultimate, on a mass basis) than regular unleaded.

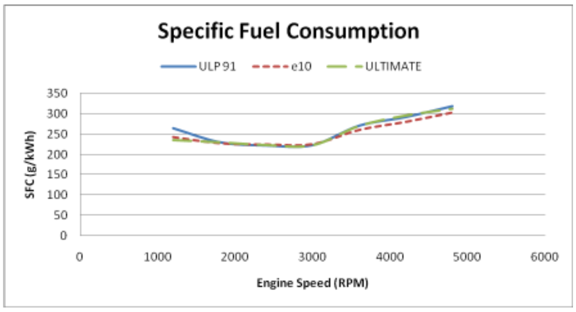

Figure 3: Comparison of the specific fuel consumption

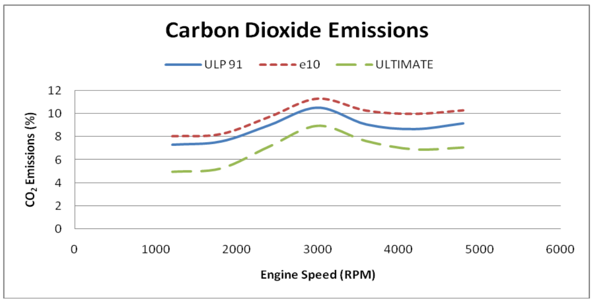

Figure 4: Comparison of carbon dioxide emissions

The analysis of combustion products (Figures 4-8) is quite difficult, as there are a number of variables which are interlinked. It is important to take a holistic approach to determining the causes of the changes in emissions, as one explanation may be contradicted by one or two of the other emissions. While the engine was running on e10, generally the carbon dioxide emissions were about 10% higher, carbon monoxide and hydrocarbons were lower, and the NO_x emissions were higher, compared with the engine running on regular unleaded. The increase in carbon dioxide coupled with the decrease in carbon monoxide emissions is a good indicator that the combustion process is good and close to completes. This is also backed up by the fact that hydrocarbons are also lower. Low levels of hydrocarbons in the exhaust gas are an indicator that almost all of the fuel is being burnt completely. The higher oxygen content of ethanol blended petrol is one possible explanation for the more complete combustion that appears to be occurring with e10.

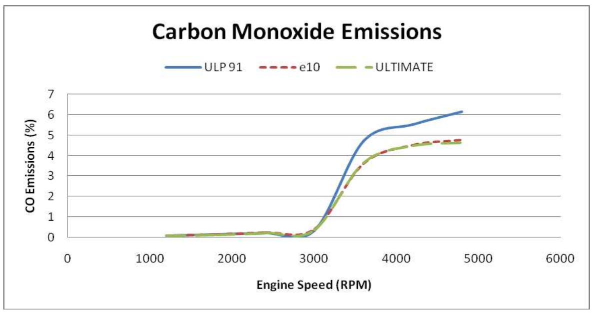

Figure 5: Comparison of carbon monoxide emissions

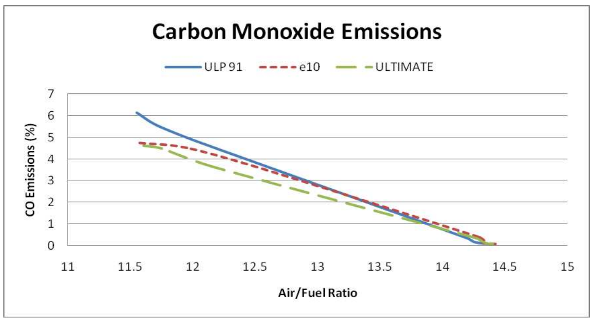

Figure 6:Comparison of carbon monoxide emissions plotted against air-fuel ratio

At higher engine speeds (above approximately 3000rpm), the air/fuel ratio becomes richer and both the carbon monoxide and hydrocarbon emissions increase dramatically

(Figures 4 and 5). This is expected at richer air/fuel ratios as there is insufficient oxygen to burn the fuel completely, and a trend that is common in the results of all of the fuels tested. The exhaust composition when combusting Ultimate unleaded is different from that of both e10 and regular unleaded fuel. There appeared to be quite a large reduction in carbon dioxide in the exhaust – down approximately 22% on regular unleaded. As well as this, the carbon monoxide emissions were also lower, and the concentration of oxygen in the exhaust gas was significantly higher. This was somewhat unexpected, as generally a reduction in carbon monoxide is closely tied with an increase in carbon dioxide. The high level of oxygen in the exhaust indicates that the air/fuel ratio is lean, i.e. there is more oxygen than is required for complete combustion to occur. This supports the fact that there are lower CO emissions, but would suggest that the CO_2 emissions should be somewhat higher (Figure 6).

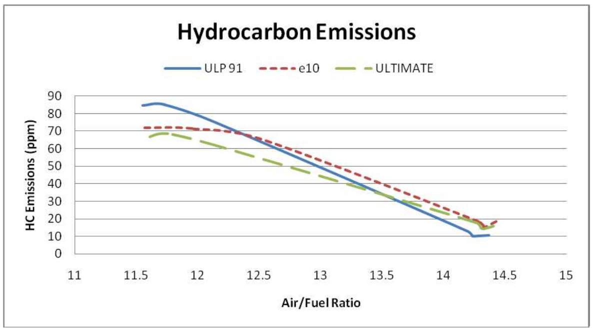

Figure 7: Comparison of hydrocarbon emissions plotted against air-fuel ratio

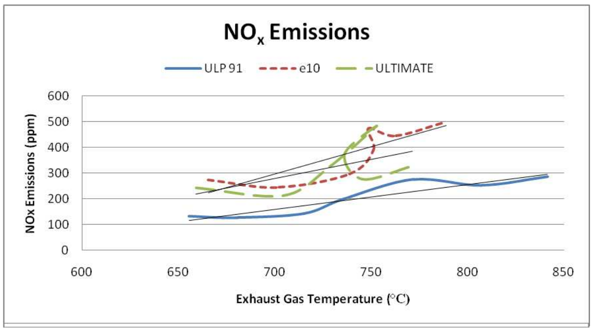

Figure 8: Comparison of NO_x emissions plotted against exhaust gas temperature

As shown in Figure 4, the CO_2 emissions are consistently well below what they are for regular unleaded and e10 indicates that Ultimate is more environmentally friendly. The lower CO and CO_2 emissions are claimed by BP to occur with the use of Ultimate. In Figure 7, the concentration of hydrocarbons is slightly down particularly at higher engine speeds. It is expected that if the combustion is almost complete, that the hydrocarbon concentration would be lower, as there is less unburnt fuel in the exhaust gas, however it must also be considered that the Ultimate has a lower Hydrogen content in the fuel than either of the other two fuels tested. As shown in Figure 8, the NO_x emissions were higher for both e10 and Ultimate than for regular unleaded. This is likely due to poor spark timing caused by the engine's knock sensor struggling to adjust to the new fuel. It is possible that if the engine was run on the new fuels for a longer period of time that the spark timing would be improved and the NO_x emissions would be reduced.

4. STATISTICAL ANALYSIS

The Wilcoxon Rank-Sum Test [11] was used to determine the statistical significance of the results. This is one way to test whether the differences in the results are explainable by variance, or whether the use of a different fuel caused significant changes. In order for this test to show statistical significance, the W values obtained must be either less than 40 (showing that the alternative fuels results are lower than the unleaded results) or greater than 65 (showing that the alternative fuels results are higher than the unleaded results). The W values obtained are shown in Table 1.

Table 1: W- value results of Wilcoxon Rank-Sum test

	Power	Torque	HC	CO	CO_2	NO_x	SFC
e10	56	58	56	51	63	72	51
Ult.	59	59	56	47	33	70	54

It is apparent that when using the Wilcoxon Rank-Sum Test as a comparison method, that the majority of the differences of results obtained are deemed to be statistically insignificant. This is partially due to the fact that this statistical test is considered quite robust, so if something is deemed significant, it is a strong result. The NO_x emissions for both Ultimate and e10 are significantly higher than for regular unleaded, and the carbon dioxide emissions for Ultimate are significantly lower than for regular unleaded. The rest of the results fall in between the values that would make them statistically significant. This does not suggest that using alternative fuels had no impact on these results, but that further testing is required to prove the existence of a relationship between the fuel and the performance and emissions.

5. CONCLUSION AND RECOMMENDATION

This study has investigated the effects on emissions and performance of a petrol engine from the use of a number of ‘alternative’ fuels. The primary reason for this study being undertaken was to determine the increase or reduction of greenhouse gases emitted, however the results obtained are based on a broader scope. The merits of using ethanol blended fuel and premium fuels were investigated, and for the most part, both fuels presented an improvement in performance and emissions over regular unleaded. As discussed above, users of the e10 fuel could expect approximately 5% improvement in power and torque, while users of Ultimate could expect approximately 6.5% improvement in these areas, compared to the use of regular unleaded petrol. The specific fuel consumption (grams of fuel consumed per kilowatt-hour of energy produced) is approximately 2.7% lower for e10 and 1.6% lower for Ultimate than was recorded for regular unleaded. This indicates an improvement in the fuel consumption, considering the power produced by the engine.

As far as exhaust emissions go, the results were less clearly defined. The e10 fuel had an 11% increase in carbon dioxide emissions and considerably higher NO_x emissions than regular unleaded, whilst the other pollutants were reduced. Ultimate appeared to be a better option in this regard, as its exhaust emissions had lower concentrations of all pollutants except for NO_x, which was in higher concentrations than in the exhaust of regular unleaded, but lower than in the exhaust of e10. Based on the results of this study, it appears that Ultimate is the best fuel of those tested, both in terms of performance and exhaust emissions. The results of this study are, however, not conclusive, and the apparent improvements obtained by using alternative fuels should serve as justification for further testing to be carried out, in order to either verify or refute these findings. It is recommended that further testing be carried out, using both the test procedure used in this study, as well as the test procedure specified in the International Standards, and that a more reliable set of equipment be used to provide more robust results.

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