Market Barriers to the Uptake of Biofuels Study

A Testing Based Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines

Report to Environment Australia

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Orbital Engine Company

CONTENTS

APPENDICES

1 Executive Summary

This document presents the findings of testing non-automotive engines with gasoline containing 10% and 20% by volume ethanol (E10 and E20), completed by Orbital Engine Company. The program is an initiative of the Environment Australia project “Market Barriers to the Uptake of Biofuels – Testing Petrol Containing 20% Ethanol (E20)”. The program comprised two components these being a desktop study and an experimental study. Both components have run in parallel.

The desktop studies were undertaken with the intent of providing further focus and substantiation to the experimental study work scope as well as providing an insight into those engine application areas that may require further consideration. These studies resulted in the submission of reports to Environment Australia covering: 1) “A Literature Review Based Assessment on the Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines” (1); and 2) “A Technical Assessment of E10 and E20 Petrol Ethanol Blends Applied to Non-Automotive Engines. Failure Mode and Effects Analysis of Engine Function and Component Design for Mercury Marine 15hp Outboard and Stihl FS45 Line-Trimmer Engines” (2). These reports have confirmed that the proposed experimental program is reasonably broad in terms of capturing the potential issues identified, though careful consideration should be given in particular to aircraft engines utilising pump gasoline.

The experimental study work scope has three major components:

- Engine performance and operability testing
- Engine durability testing
- Component material compatibility testing.

The experimental program proposed to Environment Australia via the tender submission (3) included assessment of an outboard marine and utility engine. The two engine types were selected based on being representative of the majority of non-automotive gasoline engine in each respective market segment. Additional input was through consultation with industry for identifying the representative engines. A total of nine engines were used for the study, of which there were four outboard marine engines and five line trimmer engines.

The testing of the non-automotive engines has revealed a number of concerns some of which, based on engineering judgement, are regarded as unacceptable. These unacceptable issues are related to the E20 fuel blend only.

The testing of the engines with the E10 fuel blend has in general produced no substantial impacts.

- Performance and operability testing outcomes indicated that there was comparable performance measured and observed when operating the engines on the E10 blend fuel.

- Durability testing revealed that there were two impacts of significance, the slight swelling and blistering of the Stihl engines carburettor lower diaphragm and slight increase in the build up of carbon deposits in the top piston ring groove of the piston when compared with the ULP outcome. These impacts did not however stop the engine from completing the allotted durability period with the engine performing in a similar manner at the commencement of the durability cycle.

Engineering judgement suggests that these impacts are minor and do not represent major concerns. There was no component materials compatibility testing performed with the E10 fuel blend as this was confined to the E20 fuel blend.

For the higher ethanol blended fuel (E20) it was found that both engines generally exhibited satisfactory performance, operability and base engine durability. There were however some substantial concerns within these areas as well as unsatisfactory findings for the material compatibility investigations. These concerns are outlined below.

- Performance evaluation:
    - Exhaust gas temperature has been shown to increase by a significant margin over the ULP baseline leading to potential long-term durability problems, especially with high performance engines.
    - The Mercury engine was found to stall upon WOT acceleration demand after operating the engine in a trolling test, the trolling test simulates low in gear engine operation for an extended period. It was however possible to immediately restart and operate the engine.
- Durability testing:
    - Increasing exhaust port deposits on both engines with the Stihl engine presenting with the exhaust blow-down port blocked completely. This can ultimately lead to longer term durability issues related to the increased potential for the exhaust port deposits to dislodge, get carried into the engine thereby increasing wear rates as well as leading to premature failure of the engine components.
    - The Mercury engine was found to have increased top piston ring groove carbon deposits and evidence of combustion gas blow-by on both pistons. This result has been found to be a pre-cursor to piston scuffing and subsequent major engine damage, and therefore indicates the potential for a longer-term durability concern.
    - The Stihl engine carburettor diaphragm was found to suffer severe distortion and blistering. This has the potential to result in loss of internal and external sealing which may in turn lead to fuel leakage. This result is considered unacceptable as it clearly indicates that the diaphragm material is not compatible with the E20 blend fuel.

- Materials compatibility testing:

- Metallic base engine components have exhibited corrosion of engine parts that are in contact with fuel.
    - The crankshaft seal of the Mercury engine contained rust on the metal housing.
    - The cylinder liner of the Mercury engine contained rust on the sealing surface.
    - The connecting rod of the Stihl engine contained rust on surfaces.
    - All these occurrences are considered as a concern as the potential exists for the oxide to dislodge and become trapped in between moving engine components. This situation would most likely result in accelerated wear of these components surfaces. The potential exists, depending on the severity of the oxidation and the actual final location of the dislodged oxide, to cause engine failure.
- All the brass fuel system components were tarnished indicating an oxidation process is occurring.
    - This is considered as a concern since oxidation of brass fuel and air metering jets or fuel control devices in the engine carburettor has the potential to lead to the loss of the intended nominal air metering and fuel metering or control resulting in potential degradation or loss of engine function.

- Polymeric materials were found to have significant changes on appearance due to contact with E20 fuel. The following impacts revealed from the testing are considered to be unacceptable have the potential to result in fuel leakage.
    - Fuel delivery hose of the Mercury engine has a plastic insert that was identified as distorted.
    - Fuel primer bulb of both the engines was identified as enlarged with the Stihl primer bulb enlarging by approximately 50%.
    - The Stihl engine crankshaft seal was identified as exhibiting enlargement along with loss of annular shape.
    - The fuel sight glass of the Mercury fuel tank was identified as exhibiting discolouration.

As the materials compatibility testing is ongoing, the final outcome of the testing including a quantitative analysis is planned to be reported in mid-April 2003.

2 Introduction

The Commonwealth Government of Australia, represented by Environment Australia, is investigating the effects of higher ethanol blends in fuel on the Australian vehicle fleet. This investigation is to provide information to the Government on the impacts of noxious and greenhouse emissions, vehicle performance and durability from the use of 20% by volume ethanol blended with gasoline (E20). This study will then be used to aid the Government to set the national fuel standards as provided by the *Fuel Quality Standards Act 2000*.

Environment Australia, under the auspices of the Ethanol task force, commissioned an issues paper with the aim of seeking public comment on setting the appropriate ethanol limit in automotive fuel (4). This paper extensively covered the issues related to using ethanol as an automotive fuel. In particular it refers to two earlier trials conducted in Australia. The first trial in 1980-83 (5) examined the impacts of E15 (15% ethanol). The second in 1998 (6) comprised an intensive field trial of ethanol/gasoline blend E10 (10% ethanol) in vehicles. The data from these trials, plus evidence from the submissions to the issues paper, lead to the conclusion that generally blends up to 10% are accepted as being suitable for the Australian fleet. Currently, however, there is not general consensus on the applicability of higher ethanol concentration blend fuels for the Australian vehicle fleet.

One of the conclusions that can be drawn from the submissions to the issues paper was the lack of current Australian data on the effects of higher ethanol blends (E20) on the Australian fleet. In order to rectify this, Environment Australia has commissioned testing on vehicles and components under tender No. 34/2002. Subsequently, Orbital Engine Company has been contracted by Environment Australia to undertake an engineering program related to the use of 20 percent ethanol blend fuel in the Australian market.

An identified area of application of the gasoline engine where no known current Australian data on the effects of either E10 or E20 exists was the non-automotive engine sector. To rectify this situation, Environment Australia contracted Orbital Engine Company to undertake an engineering program targeted at identifying the potential effects of E10 and E20 on the Australian population of non-automotive gasoline engines. This sub-program also falls under the tender No. 34/2002. The program activity commenced on the 17th September 2002. This report details the findings and status of program activity as of 13th January 2003.

2.1 Program Goals

The program goals were to target and identify data and information detailing the impacts of a 10 and 20 percent ethanol blend fuel on the Australian non-automotive engine fleet through both desktop and experimental studies.

2.1.1 Desktop Studies

The desktop studies investigated two areas both designed to provide focus and substantiation for the experimental studies. The first was a Failure Mode and Effects Analysis (FMEA) of ethanol gasoline fuel blends on the engines and fuel systems of the two selected engines, as well as non-automotive gasoline engines in general. This document (2) contains both a functional FMEA covering a relatively wide application of non-automotive engines and design FMEA's focussing on a Mercury 15hp outboard engine and a Stihl FS45R line trimmer engine.

The second desktop study was an "Analysis of Impacts" review (1), comprising a literature review study aimed at understanding the reasons supporting, and the potential impacts of, the use of both E10 and E20 blend fuels in non-automotive gasoline engines.

Both desktop studies have been completed and submitted to Environment Australia.

2.1.2 Experimental Studies

The goal of the experimental studies was to perform a series of structured tests designed to gather data on the effect of the baseline gasoline, the E10 and the E20 blend fuels on the following key parameters.

- Engine operability
- Engine durability
- Fuel systems and engines component materials compatibility
- Safety aspects

The information gathered from the desktop studies was utilised in designing the programs experiments in an effort to ensure that all the potential aspects received the best possible coverage within the framework of the program constraints.

2.2 Methodology Adopted

The methodology adopted for this program of work was to conduct an assessment of both engine performance and engine durability on two engines that represent their respective non-automotive gasoline engine group population. The testing was undertaken using representative baseline gasolines and 10 and 20 percent ethanol blended with the baseline gasoline. The two engine groups chosen were marine outboard and small utility.

2.2.1 Test Fuels Management

The test program requires Orbital to procure sufficient quantities of a variety of fuel types. The methodology adopted has been to source the necessary baseline gasoline and ethanol from various refiners. These fuels are then used as blend constituents to produce test fuel blends for use throughout the program. Fuel identification and usage was strictly controlled in accordance with internal Quality Assurance procedures.

2.2.2 Engine Performance Assessment

The methodology adopted to gather the experimental data was to firstly obtain an understanding of the performance of the engines on the baseline gasoline. Following this baseline, the engines were tested according to the same procedures except that the E10 and E20 ethanol blend fuel was utilised. This provides three back-to-back data sets enabling the direct comparison of the performance of each engine.

2.2.2.1 Engine Power

The testing procedure for engine power measurement was based on standards pertinent to the two engine types tested.

SAE J1228 NOV91 (7) and the Environmental Protection Agency 40 CFR part 91 (8) standards were utilised for the testing procedure for the marine outboard engine.

The procedure adopted for the utility engine testing was based on the Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 97/68/EC (9) and SAE J1088 FEB93 standards (10).

2.2.2.2 Exhaust Gas Emissions

Though no exhaust emissions regulations or testing standards for the engines tested exist for Australia, pertinent testing standards covering exhaust emissions measurement were adopted for each engine.

For the marine engine, the Environmental Protection Agency 40 CFR part 91 (8) testing procedure was adopted as closely as possible for the exhaust gas emissions measurements.

The exhaust gas emissions measurements testing procedure for the utility engine was based on both the Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 97/68/EC (9) and SAE J1088 FEB93, (10).

2.2.2.3 Engine Operability

Where possible, engine manufacturer standard testing procedures have been adopted within this area of the engine assessment. These testing procedures were determined through either Orbital’s industry knowledge or through Environment Australia approved contact with the manufacturer.

2.2.3 Engine Durability Assessment

Engine durability testing procedures were based on manufacturer testing procedures for engine durability. These testing procedures were determined through either Orbital’s industry knowledge or through Environment Australia approved contact with the manufacturer.

2.2.3.1 Engine Wear

An assessment of base engine wear was undertaken on the two engine types. The methodology adopted was a comparison of pre-identified engine components between engines run on gasoline only, the E10 blend fuel and the E20 blend fuel. Where appropriate, the engines were run-in on gasoline only according to the manufacturer’s requirements prior to the durability cycle.

2.2.4 Engine and Fuel System Material Compatibility

Materials compatibility was determined by a comparative assessment of the immersion performance of metallic, elastomeric and plastic fuel system components/samples in 0% ethanol and 20% ethanol gasoline mixes. Those base engine components that are in contact with fuel were immersed only in the 20% ethanol gasoline mixture. The methodology for testing these samples was to adopt as much as possible of the two relevant SAE standards, SAE J1747 (12) and SAE J1748 (13), that cover the materials compatibility testing. Relevant sections of the SAE standard J1681 (11) covering the details of test fuels for materials compatibility testing were also adopted where possible. The adoption was to the point of fulfilling the engineering requirement of ensuring potential incompatibility had a high probability of being identified, however the adoption was not to the point of qualification of the materials, this being outside the scope of the project.

3 Test Fuel Management

The test program required Orbital to procure sufficient quantities of fuel grade Ethanol, Unleaded Petrol (ULP) in both summer and winter grades including ULP in bulk storage on Orbital’s site. These fuels were used as the blend stocks for the preparation of the various ethanol blended fuels required for engine testing, operability and durability, and materials compatibility testing phases of the program.

Details as to the specification of and/or the actual quality of the procured fuels can be found in Appendix C.

3.1 Hot Test and Engine Performance Test Gasoline

The hot test and engine performance test gasoline was required in ULP grade and was sourced from the Caltex Kurnell refinery in New South Wales through the Caltex Broadmeadows terminal. The fuel was delivered at the beginning of November 2002. A total of eight 205L drums of ULP were received. Each drum was well labelled and accompanied with a Material Safety Data Sheet (MSDS).

The fuel was renamed for the purposes of standardization with company quality procedures and the individual drums were identified according to the following naming convention. The hot test operability and engine performance test fuel was renamed AEN Summer ULP. The individual drums have been identified with the prefix S for summer and numbered according to the number of drums in the group, ie. AEN Summer ULP S1 - S8. All performance testing except for the cold tests were completed with AEN Summer ULP neat and with E10 and E20 blended with AEN Summer ULP.

3.2 Cold Test Gasoline

The cold test gasoline was required in the ULP grade and was sourced from the Shell Newport operation in Victoria. Four drums of ULP were delivered at the beginning of November 2002. Each drum was well labelled and accompanied with a MSDS.

The fuel was renamed in accordance with the identification protocol. The individual drums have been identified with the prefix W for winter and numbered according to the number of drums in the group, ie. AEN Winter ULP W1 - W4.

3.3 Engine Run-in and Durability Gasoline

Specific test gasoline is only required for the engine performance assessment testing. For engine run-in and durability testing, pump grade gasoline is suitable. Existing supply of locally available ULP sourced from the BP Kewdale terminal in Western Australia was used for this purpose.

3.4 Engine and Fuel System Materials/Component Compatibility Gasoline

The engine and fuel system component compatibility gasoline has no specific requirements, apart from being representative of domestic fuel supply. Accordingly, the fuel used for the engine and fuel system component compatibility testing is the locally available ULP sourced from the BP Kewdale terminal in Western Australia.

3.5 Ethanol

The fuel grade ethanol was sourced from the Manildra Group in New South Wales and CSR Ltd. Yarraville Distillery in Victoria. This fuel was delivered at the end of October 2002. A total of five 205L drums were received. The packaging identified the contents as SMS 100 F21, containing one percent by volume ULP as a denaturant. The drums were marked according to the identification protocol as E1 – E5.

3.6 Gasoline/ Ethanol Mixing Process

The process used for achieving accurate, repeatable blends of the various fuel mixtures was developed by Orbital following a review of information available from organisations such as CSR, Manildra Group, American Coalition for Ethanol, Governors Ethanol Coalition and the Alternative Fuels Data Centre. The lack of explicit technical information and references to the avoidance of “splash blending” when mixing ethanol and gasoline, led Orbital to develop a mixing process based on gravimetric measurement of the blend constituents.

Drummed fuel was stored externally under a covered bunded area surrounding the bulk fuel storage facility. The drums containing the necessary blend stocks of gasoline and ethanol were transported to the fuel preparation area and soaked at 20°C for 24 hours prior to opening and decanting of fuels. The mixing process required that the densities of the fuel constituents were measured and the mass of each constituent calculated based upon the volume required to achieve the requested blend concentration. Scales were purchased with a load cell capable of measuring large masses with a high degree of accuracy. Once measured each constituent was then decanted into the blend drum. A re-circulating pump was fitted and run for a pre-determined period of time to ensure blend homogeneity. Once blended, the drum was then labelled according to the identification protocol. The batched fuel was then stored at 20°C in the fuel storage area until required for use.

3.7 Fuel Control

There were a total of 4 new fuels and blends evaluated in the various test phases of the program. An inventory of fuels specific to this program was created in an excel workbook to assist with the management and control of fuel use and location.

Of particular concern was control of the blended ethanol fuel concentrations. In order to qualify the blending process, a one-litre sample was taken from each drum of blended fuel for in-house density measurement, this was compared to a calculated value based on the density of the individual constituents. The results for the fuels used throughout this program are tabulated in Appendix C. The ethanol volume of the blends was checked in house using a basic water extraction method. A second one-litre sample was taken by a representative from the Australian Taxation Office and sent to a testing agency appointed by Environment Australia for independent analysis.

3.8 Engine Oils Used

The marine engine testing used the Mercury branded TCW3 oil in the fuel-oil premix.

The utility engine testing, as well as the materials compatibility testing on both marine and utility engine components used the Stihl branded two stroke engine oil. STIHL 2-Stroke Lube was premixed with each test fuel at the manufacturer’s recommended ratio of 50:1 by volume. This lubricant is a specially developed lubricant for air-cooled two stroke engines for mixing with leaded or unleaded petrol. The formulation utilises a mixed additive system to ensure a minimal ash deposit formulation and provides a number of performance benefits such as:

- Contains diluent, mixes easily with fuel
- Excellent corrosion control properties
- Minimal ring wear and piston scuffing
- Clean burning, assisting in maintaining cleaner combustion chambers, ports and mufflers.
- Dyed blue for easy identification.

4 Engine Performance and Durability Tests

4.1 Engine Selection

The engine selection methodology was based on selecting two engine application groups that represented the highest populations of non-automotive gasoline engines in Australia. The groups selected were the marine outboard engine and the utility engine. Consultation with manufacturers occurred to determine applications from their product range that best represented these two groups. Environment Australia approved this consultation process. For the marine outboard engine, the Mercury Marine 15 hp engine was recommended based on the highest overall sales. Within the utility engine group, the Stihl FS45R line trimmer product was recommended, as the engine is used in many other Stihl products and as such is sold in relatively high volume in Australia. Environment Australia reviewed the engine selection process and endorsed the choice of recommended product.

For the purposes of overall quality control, the engine in each product has been assigned a code. These codes will be the primary reference used throughout this report, with the last two digits referring to engine number. The selected test engines are listed in Table 4.1.1, along with a description of their primary usage.

Engine Code	Engine Type	Comments
AENME01	Mercury 15hp	Durability ULP
AENME02	Mercury 15hp	Durability E10
AENME03	Mercury 15hp	Durability E20
AENME04	Mercury 15hp	Operability testing, ULP, E10, E20
AENST01	Stihl FS45R	Operability testing, ULP, E10, E20
AENST02	Stihl FS45R	Durability ULP
AENST03	Stihl FS45R	Durability E10
AENST04	Stihl FS45R	Durability E20
AENST05	Stihl FS45R	Operability testing, ULP, E10, E20, dynamometer

Table 4.1.1 Selected Test Engines

4.2 Engine Test Description

A summary of the tests undertaken throughout the program is outlined below. Generally, for performance related testing and assessments, only one engine was used and evaluations performed with all three fuel blends. This served to isolate the influences observed to being fuelling related and not associated with engine-to-engine variability. For durability related testing, one engine was run with only one fuel blend for the required duration. Statistical confidence would be increased had there been a greater number of test engines used, however the program framework was chosen to identify any major durability issues through back to back testing for the minimum cost to the total program.

4.2.1 Engine Inspection Tasks

4.2.1.1 Engine Disassembly, Inspection and Rebuild

This process was undertaken on all the engines identified for the durability assessment. Following engine disassembly, the relevant engine components are inspected, measured and photographed as required, producing a record of the engine prior to the durability test. The engine is then rebuilt and readied for further processing.

4.2.1.2 Engine Instrumentation

In order to analyse the environmental and engine operating conditions, a variety of sensors and gas sample pipes are installed to measure system and/or ambient temperatures, pressures and exhaust A/F Ratio (Air/Fuel Ratio) and to measure exhaust gas emissions.

4.2.2 Engine Performance Tests

Engines undergoing performance evaluations were installed in dynamometer test facilities so as to allow for control and measurement of operating speed and power. These facilities were also equipped with the appropriate exhaust emission sampling systems.

Generally each engine type was characterised by means of an engine power test and an exhaust gas emissions test. As fuel blend was the key control parameter being changed during this testing, the influence that this had on exhaust gas analysis equations had to be taken into consideration. Ethanol blends have different hydrogen to carbon ratios, and oxygen to carbon ratios, than 100% gasoline fuels. The consequence is that the stoichiometric ratio for each fuel blend is different. The data analysis methods employed by Orbital takes this into account and as a result comparative A/F ratio results will be presented as equivalence-ratio, or normalised fuel-air ratio.

Engine operability performance was assessed so far as it may be influenced by the selection of fuel blend. Many of these operability tests required the product to be tested in the field and not just the engine in isolation.

4.2.2.1 Engine run-in

Engines for dynamometer evaluation were to use a dynamometer based run-in schedule as would typically be employed by the engine manufacturer.

For the marine engine, the run-in procedure was conducted until the engines reached stabilised power output as required by their respective procedures.

The utility engine was run-in prior to installation into the engine dynamometer test cell. The run-in procedure was according to the manufacturer’s recommendations detailed in the handbook available to the end user.

4.2.2.2 Engine Power

The test procedure adopted is based on SAE J1228 (7) for marine engines and corrections to standard ambient conditions are made.

The power results from the utility engines were also corrected to standard ambient conditions based on SAE J1088, (10).

The corrections compensate the power recorded during an individual test to give a standardised value based on temperature, atmospheric pressure and humidity so that tests performed at different times/days can be compared.

4.2.2.3 Exhaust Gas Emissions.

Though there are no legislated testing procedures or exhaust gas emissions levels set for non-automotive gasoline engines in Australia, exhaust gas emissions were assessed using testing standards widely adopted or proposed in foreign markets.

For the marine engine, the appropriate exhaust emissions test procedure adopted was CFR 40-91, (8). Exhaust gas analysis included use of a Hot HC FID as described by this test procedure.

For the utility engine, the appropriate exhaust emissions test procedure was the 2-point SAE J1088 (10) for handheld engines. Only dry emissions were sampled for this testing and so whilst comparative assessments can be made for the different fuel blends, the results should not be compared to the emissions limits imposed in other markets.

The testing was undertaken in an Orbital engine dynamometer test cell suited to the particular engine under test.

4.2.2.4 Operability Assessment

The engine operability was evaluated by means of tests based on either industry standards or by adopting manufacturer standards as supplied through communications with the manufacturer.

The specific tests employed were different for each engine type, marine or small utility. As such, an assessment outline will be noted along with the results presented later in this report. In general, the following areas were assessed for both engine types:

- Hot startability
- Cold startability
- Fuel tank “run-dry” re-start tests
- Transient and orientation running tests

4.2.3 Engine Durability

Both marine and utility engines were tested for an extended period in accordance to cycles either recommended by or adopted from the respective original equipment manufacturer. One engine was run on each fuel type. Each new engine was stripped as per the Engine Disassembly Inspection and Rebuild section, 4.2.1.1. This was repeated at the completion of the durability cycle.

During the test cycle, instrumentation on the engines recorded details such as operating speed, various temperatures and ambient conditions. The data logging system was set to record values from the instrumentation each time the speed / load condition was changed. The cycle change was initiated by the same system and achieved by remotely operating the throttle of each engine. These details were examined and compared after the completion of the testing for variation and trends.

4.2.3.1 Marine Engine

A 300hour test comprising a cycle adopted from the manufacturer’s dock endurance test was utilised. The cycle called for the operation of the engine at rated speed for 55minutes followed by 5minutes at idle, repeated until the engines reached the required number of test hours. To ensure each engine ran to the same rated speed, specific propellers were selected to “trim” the engines.

All engines were run concurrently next to each other in a dedicated marine tank (see Figure 4.2.1). The geometry and water volume of the tank, as well as the spacing between the engines, was selected such that the effect of water motion from one engine to another was minimised as much as practicable or as according to manufacturer’s specifications where possible.

Figure 4.2.1 Marine Engine Durability Testing

The engines were stopped once a day for refuelling. A cursory inspection made and any noteworthy observations recorded in the test log book and where necessary also documented with photographs etc.

The durability cycle for marine outboard engines can be up to 1000 hours in duration.

4.2.3.2 Utility Engine

A 100hour test cycle used was adopted in consultation with the manufacturer. The cycle called for the operation of the engines at rated speed for 306seconds followed by idle for 54seconds, repeated until the required test hours are reached. Rated speed for these line trimmer engines was achieved by individually adjusting the length of the trim line. The set-up of theses engines was as per the manufacturer’s recommendations.

All engines were run in series in the same durability test cell, as such each engine was exposed to ambient conditions as automatically controlled by the conditioned air system.

Elevation View

Plan View

Figure 4.2.2 Utility Engine Durability Testing

The engines were stopped once a day for refuelling. A cursory inspection made and any noteworthy observations recorded in the test log book and where necessary also documented with photographs etc. Additionally, a cold compression test was performed on each of the engines and the results recorded in the log book.

5 Engine Performance and Durability Results

5.1 Marine Engine

A summary of the performance and durability tests undertaken is discussed below. Test reports for each engine test are included in the appendices to this report.

5.1.1 Engine Performance

Detailed test reports are included at Appendix A. A summary of test findings is provided in the following subsections. All engine performance tests for Wide Open Throttle (WOT) power and emissions were conducted for each of the three fuel blends under investigation, ULP, E10 and E20, whilst engine run-in was performed using ULP. The Mercury 15hp engine requires a pre-mixed fuel of 50:1 fuel:oil ratio.

5.1.1.1 Dynamometer Based Performance

All dynamometer performance tests were conducted using the one engine (AENME04) run in the same facility to ensure consistency. Marine engine testing requires that the outboard assembly consisting of engine and gearcase be assembled in a water-filled tank and the output shaft (where normally the propeller would be) coupled to the dynamometer (see Figure 5.1.1). The use of a water-filled tank ensures that the engine receives its coolant in the normal method via suction from the base of the leg. A water replenishment scheme is used to ensure that the temperature of the water in the tank does not unduly rise.

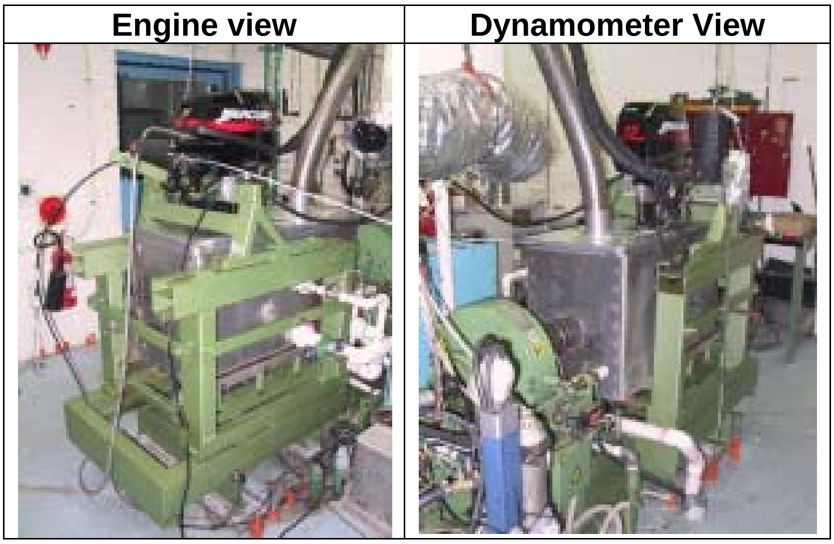

Engine view **Dynamometer View**

Figure 5.1.1 Marine Engine Dynamometer Installation

5.1.1.1.1 Engine Run-in

The engine used for dynamometer based performance and emissions followed the manufacturer’s recommended engine break-in procedure as required for dynamometer run-in. During the first fuel tank of operation, the fuel:oil ratio was set at 25:1. Subsequent running was performed with a 50:1 fuel:oil ratio.

The run-in procedure was conducted in two phases, the first of 90minutes duration involved cycling through different speed and part-load throttle positions as outlined in
Table 5.1.1 below:

Engine speed (rpm)	Set Engine torque (Nm)	Duration (minutes)
3000	11	20
3500	14	25
4000	16	20
4500	18	25
Total duration (minutes)		90

Table 5.1.1 Engine Run-in (1st Phase)

The second run-in phase required the engine be run at Wide Open Throttle (WOT) switching between 5000 and 5500rpm every 15minutes until torque stabilisation was achieved.

After a total of 3hrs of run-in the WOT torque was deemed to have stabilised. Checks were made to ensure that the engine was operating normally, with no system/component failures detected throughout the test. The engine was cleared for further testing.

Further test results and details are contained in the Test Report attached as Appendix A-1.

5.1.1.1.2 Engine Power

WOT Performance was assessed for each of the three fuel blends in the 2000 to 6000rpm range in increments of 500rpm.

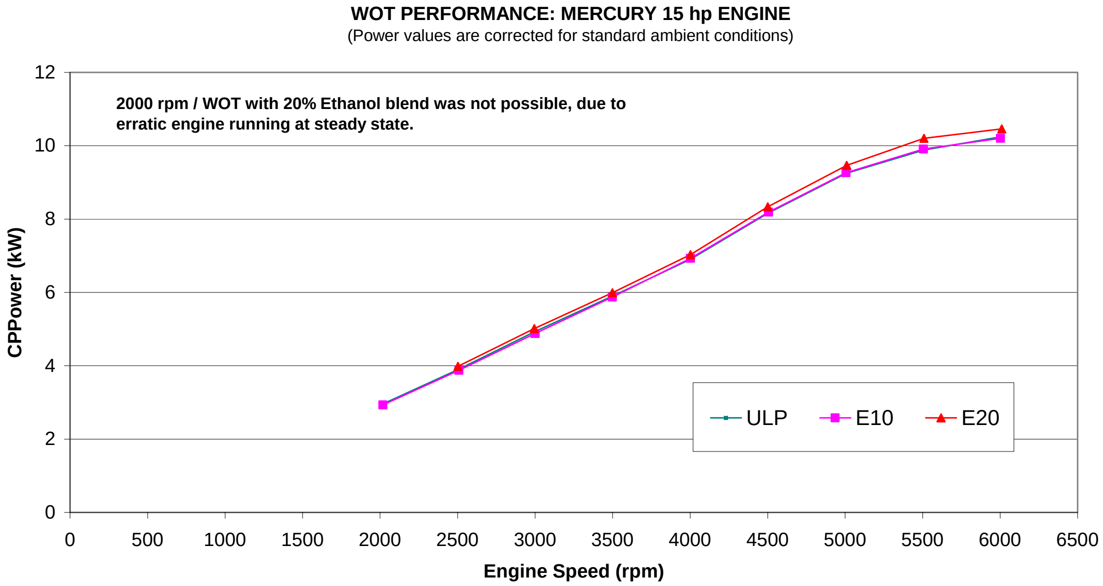


Figure 5.1.2 Marine Engine WOT Power Results

Figure 5.1.2 indicates that the performance is similar for ULP and E10. Power when operating with E20 is consistently higher than with the other fuel blends by between 1 to 3%. Closer examination of the recorded data confirms that for the given carburettor setting, the resulting equivalence ratio with E20 is leaner than for ULP and E10 tests and more closely matches the “best torque” calibration. The majority of two stroke engine manufacturers specify “rich of best torque” settings to provide tolerance to a range of operating factors and improve engine reliability. However, it was not possible to record E20 results for the 2000rpm point due to the very erratic operation of engine potentially caused by operation at leaner than stoichiometric A/F ratio conditions (see section.5.1.1.1.3).

Further test results and charts are contained in the Test Report attached as Appendix A-2.

5.1.1.1.3 Enleanment during Engine Power Test

The addition of ethanol to the fuel blend has the effect of increasing the enleanment of the combustion process providing the fuel metering control remains constant. The value of enleanment can be theoretically calculated from the fuel and ethanol properties and mixing ratio. The theoretical enleanment is compared to the measured results at one point in the engine power test and shows reasonably good correlation between measured and theoretical equivalence ratios, see Figure 5.1.3. The theoretical issues related to enleanment can be reviewed in (1).

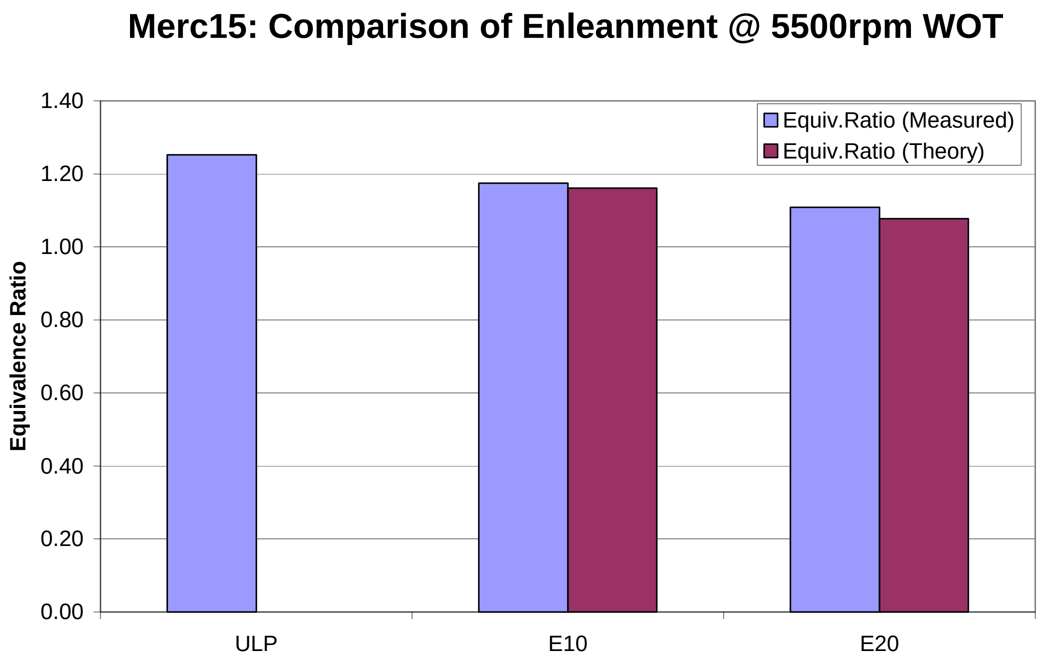


Figure 5.1.3 Marine Engine Enleanment Results – Power Test

The measured equivalence ratio throughout the engine operating range is shown in Figure 5.1.4. Stoichiometric engine operation occurs at an equivalence ratio of 1.0, which for the E20 fuel blend is reached at the 2500rpm point. At the 2000rpm point the equivalence ratio is expected to be leaner, resulting in conditions that are unsuitable for the stoichiometric or richer homogeneous combustion conditions required for this particular engine design.

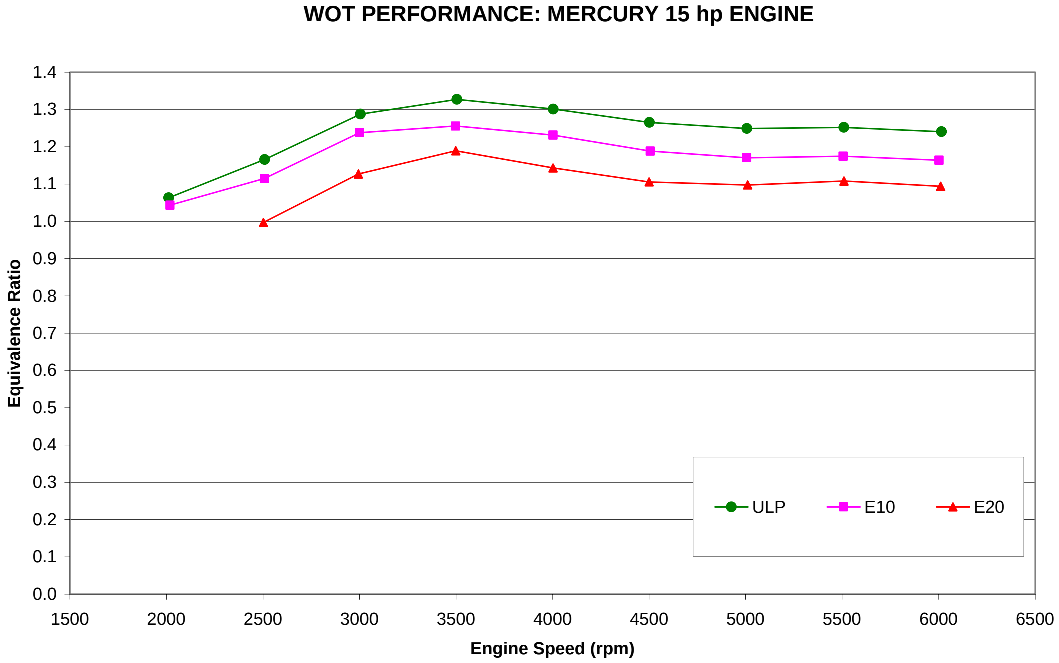


Figure 5.1.4 Marine Engine Equivalence Ratio for WOT Tests

The data gathered during the investigations also confirmed the expectation that exhaust gas temperatures would rise as a result of operation on ethanol blended fuels. The data in Figure 5.1.5 shows the exhaust port gas temperature results for both cylinder #1 and #2. There is a clear trend of increasing exhaust gas temperature as a function of increasing ethanol content in the fuel blend. The magnitude of temperature increase is of the order of 30^{o}C for 20% ethanol. The trend is similar for both cylinders, with cylinder #2 temperatures being higher than those of cylinder #1. The cylinder to cylinder variation is possibly due to a number of factors but could be related to coolant flow within the engine and the precision to which the thermocouples were located.

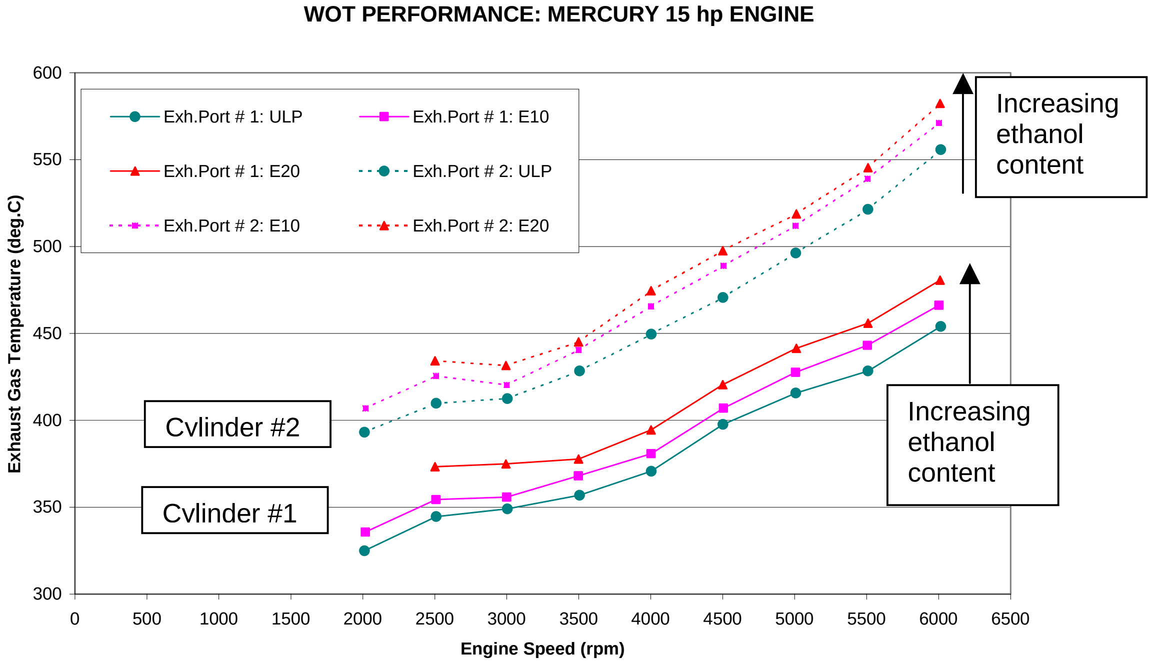


Figure 5.1.5 Marine Engine WOT Exhaust Temperatures

5.1.1.1.4 Exhaust Gas Emissions

Exhaust gas emissions tests were conducted in accordance to the procedure outlined in CFR 40-91. In summary, this procedure calls for wet (or often also referred to as "hot") Hydrocarbon emissions sampling and dry sampling of the other emissions constituents at five (5) engine operating points. The five operating points (test modes) are factorings of the engine's rated speed and load, and include idle. Results from each test point are aggregated using a weighting factor to produce a composite result. The speed and load set points calculated for the Mercury 15hp engine are as summarised in Table 5.1.2 below:

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Speed (rpm)	5500 (rated speed)	4400	3300	2200	725 (Idle)
Torque (Nm)	17.5	12.5	8.2	4.4	No Load
Weighting factor	0.06	0.14	0.15	0.25	0.4

Table 5.1.2 Mercury 15hp CFR 40-91 Test Points

The "Cycle Weighted" results from the CFR 40-91 emission tests from the three different fuel blends are shown in the Table 5.1.3 below:

Fuel Type	ULP	E10	E20
Ave. Weighted FC (g/kWh)	813.4	792.4	800.8
Ave. Weighted HC (g/kWh)	225.1	211.8	213.2
Ave. Weighted NOx (g/kWh)	0.89	0.95	1.7
Ave. Weighted CO (g/kWh)	407.1	329.5	221.7
Ave. Weighted HC + NOx (g/kWh)	226.0	212.8	214.9

Table 5.1.3 Marine Cycle Weighted Emissions and Fuel Consumption Results

The data shows a clear trend in the reduction of CO emissions with a concomitant increase in NOx as the ethanol content is increased in the fuel blend. This trend is supported by examination of the equivalence ratio (normalised fuel-air ratio) that confirms the E20 blend results in the engine running appreciably leaner than the other two fuels.

This trend however is evident in the results for hydrocarbons. Closer examination of the results mode-by-mode indicates that at mode 4, the E20 blend is operating lean beyond the limits of the engine normal operating limit and thus results in appreciable combustion variability evident as speed and torque fluctuation. This combustion variability cause hydrocarbon emissions for this particular fuel / mode to increase (see Figure 5.1.6):

The fuel consumption results are similar to the hydrocarbon results, with the mode 4 point biasing the overall trend see Figure 5.1.7.

Further test results and charts are contained in the Test Report attached as Appendix A-3.

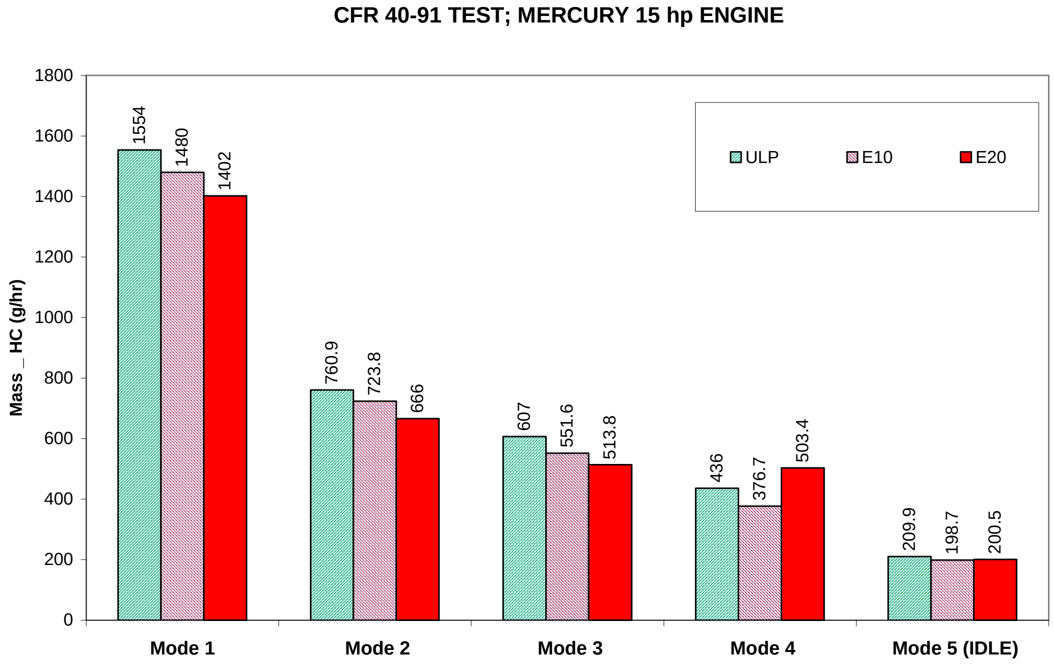


Figure 5.1.6 Marine Weighted Modal HC Emissions Results

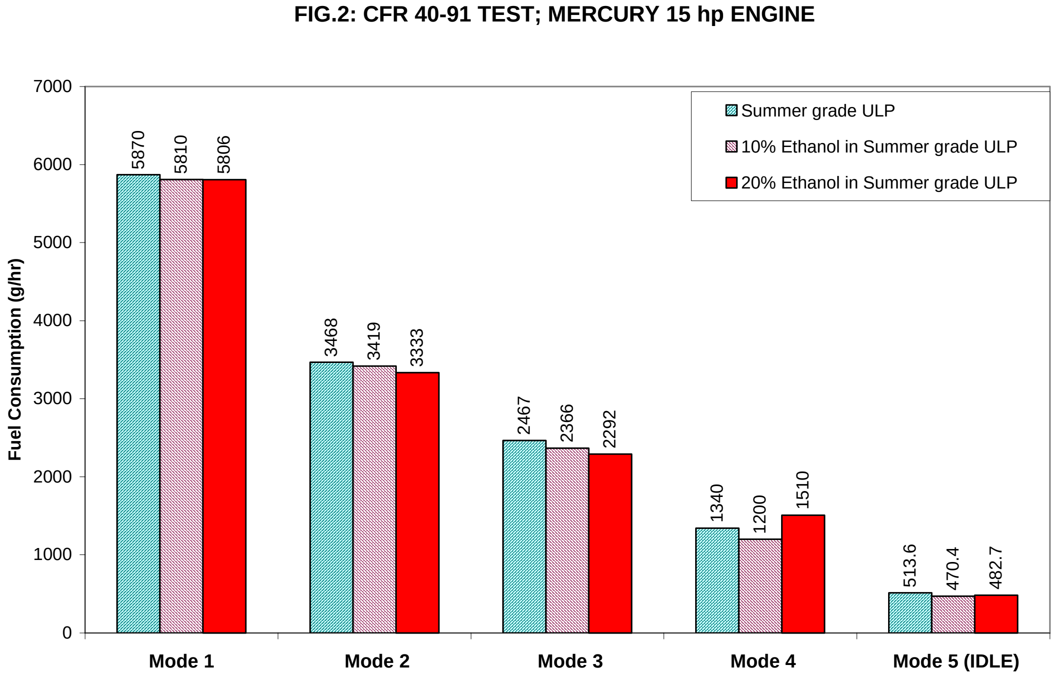


Figure 5.1.7 Marine Fuel Consumption Results

5.1.1.1.5 Enleanment during Exhaust Gas Emissions Test

As was observed for the WOT test results, comparison of theoretical and measured equivalence ratios at Mode1 (essentially a repeat of the WOT comparison) is aligned. The results shown in Figure 5.1.8 compare well to those of Figure 5.1.3.

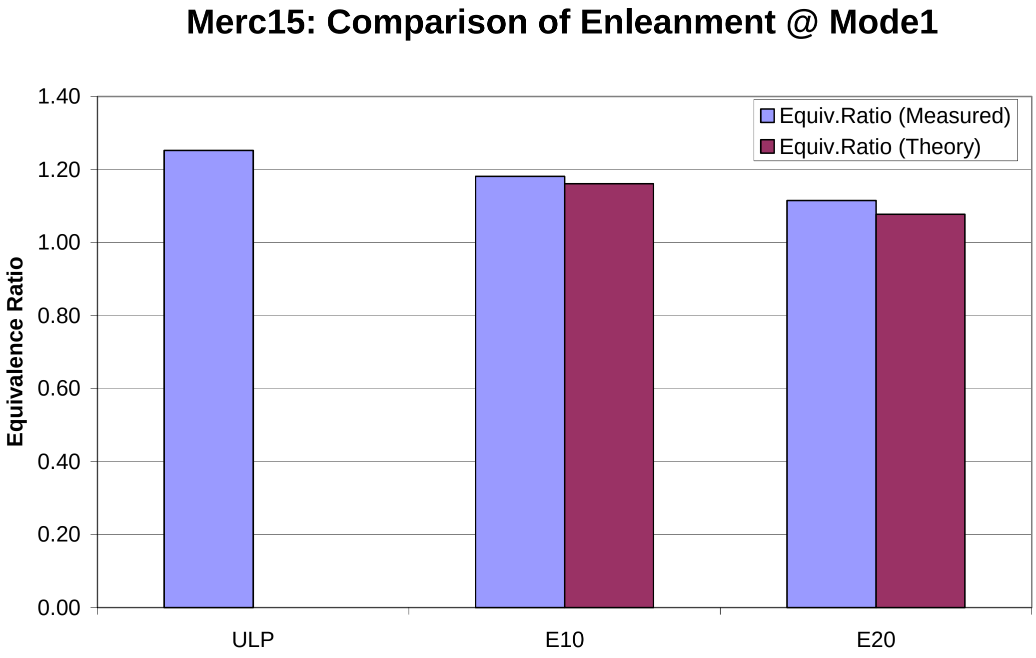


Figure 5.1.8 Marine Engine Enleanment Results – Emissions Test

5.1.1.1.6 Discussion

The dynamometer based performance tests highlight that whilst the engine continued to operate with an A/F ratio resulting in a mixture strength that was at, or richer than, the stoichiometric value, it would perform with acceptable results. The baseline carburettor set-point was such that the performance with E10 fuel did not highlight any performance concerns, with WOT performance being comparable and emissions and fuel economy marginally better than the ULP baseline.

Use of the E20 fuel highlighted issues with the setting of the carburettor at an engine speed of approximately 2000rpm, both at part load and at WOT conditions. At this speed, the engine ran appreciably lean resulting in erratic combustion quality, as is typical of lean operation on an engine designed for stoichiometric or richer homogeneous operation. It must be remembered that the carburettor was set for operation according to the manufacturer's recommendations with ULP.

The effect of enleanment is also characterised by the increase in exhaust gas temperatures. Enrichment of the fuel air mixture at WOT operation of engines is an industry standard method for controlling exhaust gas temperatures. This is achieved by effectively utilising the excess fuel to absorb some of the energy released during combustion thereby reducing the temperature of the combustion gas and subsequently the exhaust gas. This provides a powerful tool in controlling the operating temperature of all the base engine components that are in contact with the combustion gases and subsequently the exhaust gases. The exhaust gas temperature increase measured for the engine while operating on the E20 blend fuel is considered to be significant. Should the engine have a lean mixture setting while operating on ULP only, the temperature increase to the exhaust gas through further enleanment from the E20 blend has the potential to raise the exhaust gas temperature to a point where base engine components, particularly the piston, may fail due to thermal overload leading to a catastrophic engine failure.

5.1.1.2 Operability Assessment

The same engine used for the dynamometer assessments was used in the assessment of operability. Operability tests were conducted with the engine either fitted to a mobile marine tank or to a boat, as appropriate for the test. Were necessary a portable logging system was used to record engine speed and key temperature parameters. The data logging was complemented by the use of a Digital Storage Oscilloscope. Although the operability assessment is predominantly subjective, the procedures adopted represent industry respected methods.

The start tests conducted at non-ambient conditions were performed using an Environmental Testcell to provide temperature control at both 40^{o}C and 0^{o}C, during hot and cold soak tests respectively. During the hot soak tests, solar heating lamps were used to provide direct heating to the engine cowl simulating solar heat input.

5.1.1.2.1 Hot Start

The procedure followed for the hot start was to pre-condition the engine by operating the engine at a fast idle in a portable small tank until the under cowl temperature stabilises at 50^{o}C and the tank water temperature reaches at least 40°C. The engine is then switched off and soaked for a period to allow heat flow from the engine block into the under cowl cavity until the under cowl temperature stabilises at 55 to 60°C. The heat soaking was undertaken in the environmental test cell that was stabilised at 40°C with the engine positioned under the solar heating lamps (see Figure 5.1.9).

Figure 5.1.9 Marine Engine undergoing Hot Soak

The engine started with the first pull for all three fuel blends tested.

At this elevated ambient temperature there was a tendency even with ULP for the engine "fast" and "normal" idle to exhibit variable run quality. It was observed that there was a tendency for approximately half the post-start idles to exhibit smooth operation whilst the other starts exhibited idle operation with excessive engine speed fluctuation and increased engine speed. The idle quality would in all cases be subjectively rated as "acceptable" for an engine in this class.

E10 test results suggest that there was no perceptible difference in the randomness of idle behaviour when compared to the performance with ULP. Close examination of logged data does confirm a minor increase in the average idle engine speed and amplitude of the fluctuations of engine speed.

E20 post-start idle was in all cases characterised by an increase in idle engine speed and engine speed fluctuation. Subjectively, however, E20 idle performance was rated as "acceptable".

The results of the logged data in terms of idle engine speed and fluctuations are summarised in the following two tables (Table 5.1.4 and Table 5.1.5).

	Fuel Type		
Idle Speed Condition	**ULP**	**E10**	**E20**
Fast idle engine speed (rpm)	1600	1728	2110
Normal idle engine speed (rpm)	890	1018	1285

	Fuel Type		
Idle Speed Condition	**ULP**	**E10**	**E20**
Fast idle engine speed fluctuation (rpm)	+/-445	+/-352	+/-500
Normal idle engine speed fluctuation (rpm)	+/-145	+/-252	+/-375

Table 5.1.5 Hot Start Fast and Normal Idle Engine Speed Fluctuation

Further test results and charts are contained in the Test Report attached as Appendix A-4.

5.1.1.2.2 Cold Start

Cold start testing on the marine engine was conducted with the engine having been soaked for a minimum of 8 hours at 0^{o}C in the Environmental Testcell. As the mobile marine tank was used, a small quantity of Glycol (20%) was mixed in with the tank water to prevent freezing.

The engine started with the first pull for all three fuel blends tested.

The engine's “fast idle” exhibited poor run quality with all fuel types at this low ambient temperature. There was a tendency with ULP for the engine to continue running poorly even after the engine was switched to “normal” idle.

Tests with the ethanol blend fuels demonstrated improved “normal” idle run quality. With these fuels, both average idle engine speed and the frequency and severity of idle engine speed fluctuations was reduced. There was no discernable difference in the performance between E10 and E20.

The results of the logged data in terms of idle engine speed and fluctuations are summarised in the following two tables (Table 5.1.6 and Table 5.1.7).

	Fuel Type		
Idle Speed Condition	**ULP**	**E10**	**E20**
Fast idle engine speed (rpm)	2018	1945	2000
Normal idle engine speed (rpm)	1298	995	1020

Table 5.1.6 Cold Start Fast and Normal Average Idle Engine Speed

	Fuel Type		
Idle Speed Condition	**ULP**	**E10**	**E20**
Fast idle engine speed fluctuation (rpm)	+/-888	+/-530	+/-475
Normal idle engine speed fluctuation (rpm)	+/-388	+/-230	+/-255

Table 5.1.7 Cold Start Fast and Normal Idle Engine Speed Fluctuation

Further test results and charts are contained in the Test Report attached as Appendix A-5.

5.1.1.2.3 On-Water Driveability

On-water driveability with the three fuel blends was assessed using the industry accepted “Jury Test” subjective rating system (see Table 5.1.8). Various aspects of driveability were rated as well as fuel tank “run-dry” startability. Additionally, data was logged as appropriate to confirm details such as peak engine speed reached. It should be noted that for this small engine category, boat loadings such as number of occupants and water conditions are likely to have a significant influence on measured results. As a consequence, it is general acknowledged practice to only rate some performance factors such as acceleration for smoothness of operation and not for specific acceleration times.

No.	ASSESSMENT	PERCEPTABLE TO
1	Not Acceptable	Anybody
2	Not Acceptable	Average Customer
3	Not Acceptable	Average Customer
4	Objectionable	Average Customer
5	Borderline	Critical Customer
6	Barely Acceptable	Critical Customer
7	Fair	Critical Customer
8	Good	Critical Customer
9	Very Good	Critical Customer
10	Excellent	Trained Observer

Table 5.1.8 “Jury Test” rating scale

The data in Table 5.1.9 below is a summary of the areas assessed by the Jury Test method and the average of the ratings assigned.

	Ratings for Fuel Type		
Driveability	**ULP**	**E10**	**E20**
1) Docking/Manoeuvring	8	8	7.75
2) Fast Shift	8	8	8.5
3) Vibration	6.5	6.5	6.5
4) Smoke	7	7	7.5
5) Noise	7	7	7
6) Idle	7	7	7
7) Trolling	7	6	5.75
8) Steering and Tilt	7	7	6
9a) Fast Acceleration	7	8	8
9b) Slow Acceleration	7	8	8
Re-Fuel Start “run dry”			
# Pulls to Start	1	1	1
Rating	8	8	8

Table 5.1.9 Average “Jury Test” ratings for on-water driveability

The rating for most performance factors is within the variability limits of the assessment method. The variations in rating for 1), 2) and 4) are to be considered insignificant and essentially translate to acceptably good performance.

The main areas where there was a consistent trend in performance change were the extended trolling test 7) and the steering / tilt test 8). The changes would typically only be identifiable by the critical observer.

Extended trolling resulted in an increase in the frequency of misfires. The misfire tendency increased more with the increase in ethanol content in the fuel blend, though not to an objectionable level. With the E20 fuel blend however it was not possible to accelerate the engine without stall after the extended troll. The failing is expected to be related to the combination of the hot fuel handling performance of the carburettor and the sudden lean condition induced by the opening of throttle.

With the fuel tank "run-dry" simulation tests, the engine started "first pull" for each fuel types confirming that this was not an identifiable performance concern.

Further test results and charts are contained in the Test Report attached as Appendix A-6.

5.1.1.2.4 Discussion

Operability as assessed by this series of objective and subjective tests was generally acceptable for all fuel types.

The engine would start first pull with all fuel types regardless of hot or cold pre-conditioning. Idle quality following the start was in some cases worse, but in none of the tests was it characterised as being unacceptable. With a hot start, there was a trend of increases in the average idle engine speed and a general trend of increasing amplitude of the engine speed fluctuations as a result of increases in ethanol content as compared to ULP. With a cold start, the trend was the reverse with ethanol blends improving the engine idle quality when compared to ULP operation.

Subjective on-water driveability tests on the whole did not identify great number of concerns with generally good performance and no flat spots during acceleration runs. Two exceptions to this were an increase in the frequency of misfires during the extended trolling and tilt manoeuvres with increases in proportion of ethanol in the fuel, as well as, a situation identified with E20 where following the extended trolling test it was not possible to accelerate the engine without stalling. This behaviour was repeatable and the only engine function identified in all the operability tests that could be considered objectionable. The exact mechanism was not isolated, but in considering some of the results from the test cell performance evaluations and the ambient conditions, it is likely to be a combination of carburettor hot fuel handling (fuel volatility influence, see (1)) and the excessively lean (enleanment, see (1)) engine operation that is induced when opening the throttle fully. Upon the engine stalling it was possible to restart immediately with one pull on the starter cable, accelerate and drive away.

5.1.2 Engine Durability

All three engines completed the 300hour test cycle with no failures recorded.

The details from the pre and post strip downs are contained in the Engine Strip Reports attached as an Appendix.

Test Report A-7 attached examines the data in the individual Strip Reports and provides details such as calculation of wear and observations.

From the data logged during the durability cycle it is clear that all three engines completed the same duty cycle and test hours and reached similar speeds during the WOT phase, see Figure 5.1.10.

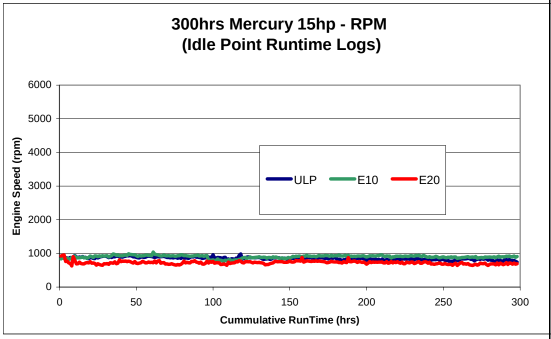
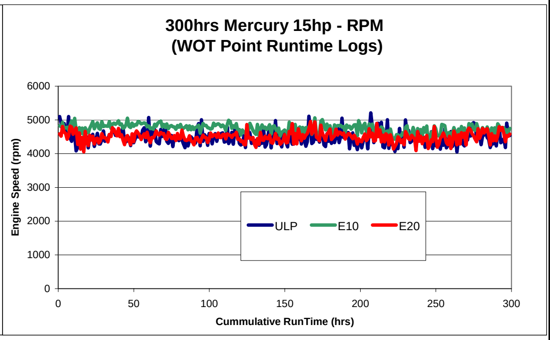
Idle Speed log points	**WOT Log Points**
	

Figure 5.1.10 Marine Engine 300hr Test Log

5.1.2.1 Base Engine Wear

Measurements were made of all key base engine components, and wear calculated as the change from pre to post dimensions. The wear for all three engines was compared and found to be within acceptable limits, based on the data in Test Report A-7. A complete listing of measured parameters is included as an attachment to Test Report A-7, a summary of this data for all three fuels is provided in Table 5.1.10.

Component	**Wear**
Piston skirt	0-20μm
Cylinder bore	0-50 μm
Piston ring gap (top)	150-300 μm
Piston ring gap (2nd)	50-100 μm
Piston groove clearance	No change
Piston ring thickness	30-140 μm
Piston pin and pin bore	0-6 μm
Small end, big end & main clearance increase	0-10 μm
Connecting rod thrust washer	0-100 μm

Table 5.1.10 Summary of Marine engine wear

There was no evidence of there being specific base engine wear that was associated with a particular fuel type.

5.1.2.2 Engine Deposits

General deposit formation on the engines was acceptable regardless of the fuel blend. There are some areas identified where deposit formation should be specifically commented upon, but these were not seen to cause operational problems during the durability testing.

The first area is the exhaust port of the engine. There was marginally more deposit formation in the exhaust port of the engine run with E20 blend than in the engines operated with ULP or E10 (see Figure 5.1.11). It was not however enough of a difference to raise undue concern.

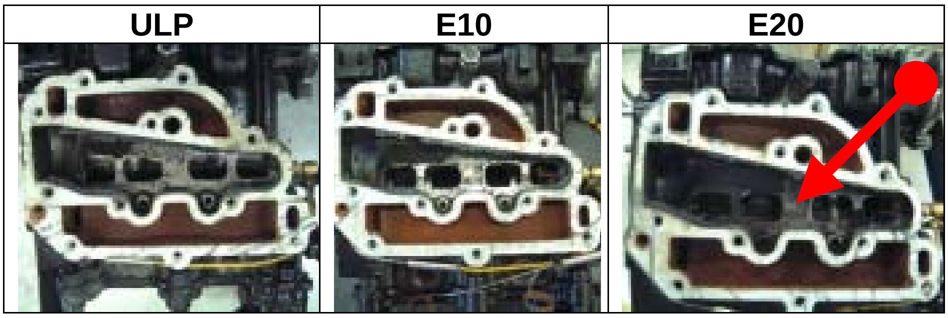


Figure 5.1.11 Marine Engine Exhaust Port Deposit Condition

The second area is carbon deposit formation on the top piston ring land. The ULP engine exhibited a clean appearance with very little combustion gas blow-by marking only on the piston for cylinder #1, (the details of blow-by will be explained in section 5.1.2.5). E10 and E20 engines had progressively higher top ring land carbon deposits on both piston #1 and #2, and for the E20 fuel, some evidence of increased combustion gas blow-by especially on piston #1 (see Figure 5.1.12). Whilst the conditions are acceptable, the difference is highlighted as this is a critical region for the longer term durability of this engine type. Examination of the exhaust port gas temperatures (see Figure 5.1.13) confirms the trend reported during performance evaluations, with exhaust gas temperature increasing with increases in ethanol content see Figure 5.1.5.

	ULP	E10	E20
Cylinder #1			
Cylinder #2			

Figure 5.1.12 Marine Engine Piston Ring Land Deposit Condition

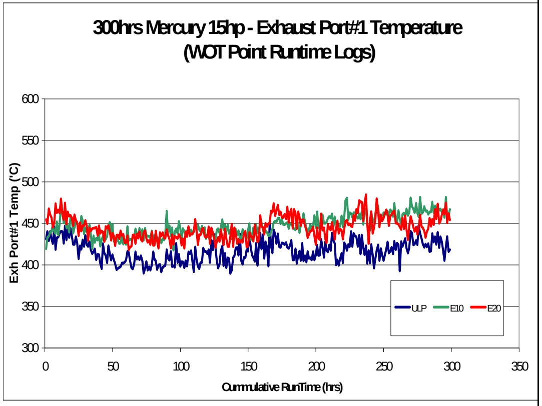
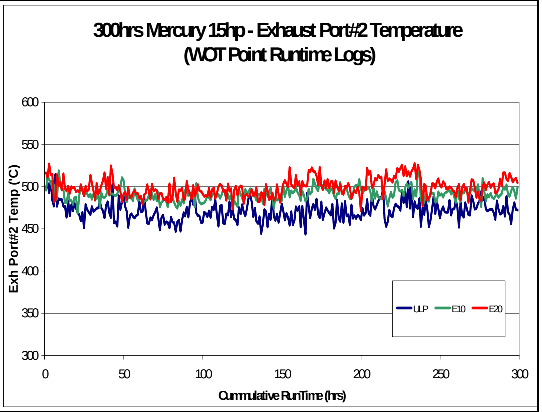
Exhaust Port #1 Comparison	Exhaust Port #2 Comparison
	

Figure 5.1.13 Marine Engine Exhaust Port Temperatures @ WOT

Sparkplug deposits are similar for ULP / E10 / E20 fuel. All spark plugs show a high level of electrode wear which is typical for this type of testing. All plugs wore by a similar amount regardless of fuel blend being used.

5.1.2.3 Fuel System Durability

The fuel system was inspected including disassembly and examination of the membranes within the carburetor. No specific fuel system durability problems were found.

5.1.2.4 Fuel System Deposits

Fuel system deposit formation on all 3 engines after completion of the durability test was determined as acceptable.

5.1.2.5 Discussion

All three engines completed the required 300hr durability test cycle with the respective fuel blend. All were seen to be performing comparably at the end of the test period as could be judged by examining their ability to reach comparable WOT speeds.

Formal assessments of component wear and visual inspection of components found that:

- Wear was within acceptable limits for all three engines with no specific bias to one fuel blend over another.
- Engine deposits were acceptable for all three engines, though there was evidence to suggest a trend of increasing top ring land deposits and evidence of an increase in combustion gas blow-by as ethanol content in the fuel increased. Marginally more deposit formation in the exhaust port was noted.
- Fuel system durability was acceptable with no notable deposit formation evident

It should be noted that the above summary is based on a sample of one engine per fuel type, and as a consequence, the drawing of any specific conclusions about trends as a function of fuel type relies strongly on the assumption that the individual base engines would have performed equally had they be tested on the same fuel type.

The combustion gas blow-by trend noted requires further discussion as it has a critical bearing on engine durability. Firstly, the terminology refers to a condition where the hot combustion gases usually contained in the combustion space escape past the piston rings. The evidence is presented as markings on the piston skirt as shown in Figure 5.1.12 for the E20 fuel. Typically top ring land deposits and increases in combustion gas blow-by are pre-cursers to catastrophic engine failure. The ring land deposits grow to a point where the piston ring is trapped, (known as “ring stick”), not allowing the piston ring to move freely against the cylinder wall and thereby not sealing the combustion space properly. The result is that hot combustion gases are allowed to escape past the piston ring and make contact with the skirt of the piston, thereby increasing the temperature of the piston in this area. This process has the potential of increasing the temperature of the piston skirt area to the point where lubricant failure occurs causing major engine failure. The effect of enleanment through the use of the E20 fuel blend only adds to the potential durability issue through the higher exhaust gas temperatures associated with enleanment and therefore combustion gas temperatures. Strong evidence of the potential for longer term engine durability problems can be seen from the data collected while operating the engine on the E20 fuel blend.

5.2 Utility Engine

A summary of the performance tests undertaken to date are discussed below. Test reports for each engine test are included in the appendices to this report.

5.2.1 Engine Performance

Detailed test reports are included at Appendix B. A summary of test findings is provided in the following subsections. All engine performance tests for WOT power and emissions were conducted for each of the three fuel blends under investigation; ULP, E10 and E20, whilst engine run-in was performed using ULP. The Stihl FS45R engine requires a pre-mixed fuel of 50:1 fuel:oil ratio.

5.2.1.1 Dynamometer Based Performance

All dynamometer performance tests were conducted using the one engine (AENST05) run in the same facility to ensure consistency. Utility engine testing requires that the engine assembly consisting of engine and drive output shaft be assembled and coupled to the dynamometer (see Figure 5.2.1). The assembly thus includes the utility engines drive coupling/clutch and care must be taken to identify any slippage, particularly at low speed.

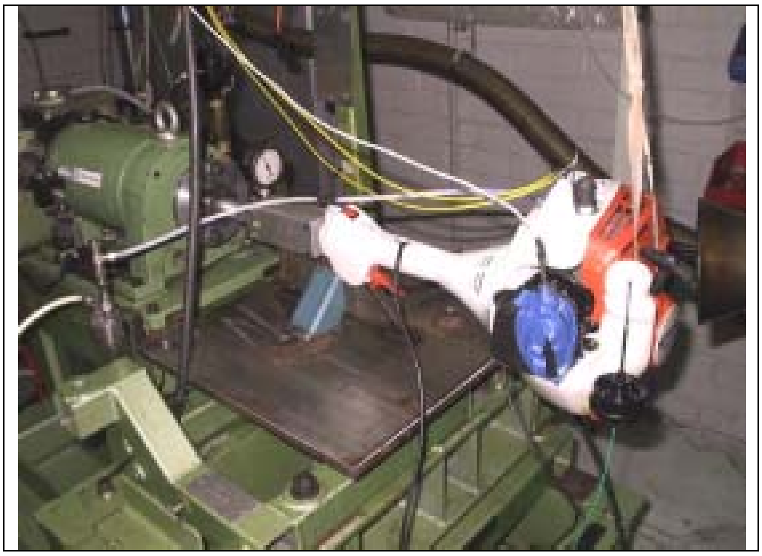


Figure 5.2.1 Utility Engine Dynamometer Testing

5.2.1.1.1 Engine Run-in

The engine used for dynamometer based performance and emissions followed the manufacturer's recommended engine break-in procedure however this run-in was conducted prior to installation of the engine to the dynamometer. The run-in was conducted using ULP with the prescribed 50:1 fuel:oil pre-mix.

5.2.1.1.2 Engine Power

WOT performance was assessed in the range of 4000 to 9500rpm in increments of 500, for each of the three fuel blends. Evident clutch slippage at low speed meant that only results from 5000rpm upwards could be compared in detail. Results from two engine power tests on each fuel were averaged to overcome some of the variability found when testing this engine, and it is this average that is presented in this report.

The carburettor fitted to the Stihl engine tested allows the "high speed" operating mixture to be adjusted to one of seven discrete settings (settings "1" through “7”, with “1” being the richest and “7” being the leanest mixture setting). Prior to embarking on the study to compare fuel types, the influence of this adjustment was characterised and a baseline setting chosen for all subsequent testing. The characterisation was conducted with ULP as the fuel, and even though the testing was conducted in relatively short span of time to minimise changes to ambient conditions, the repeatability of setting “7” highlighted variation of the order of 7% (or +/-4% from mean). Although setting “5” was selected for all subsequent performance and emissions tests, based on acceptable torque and air fuel ratio measurement, the variability noted here was also seen with other preparatory tests on this engine, making clear conclusions difficult to draw from a limited data set.

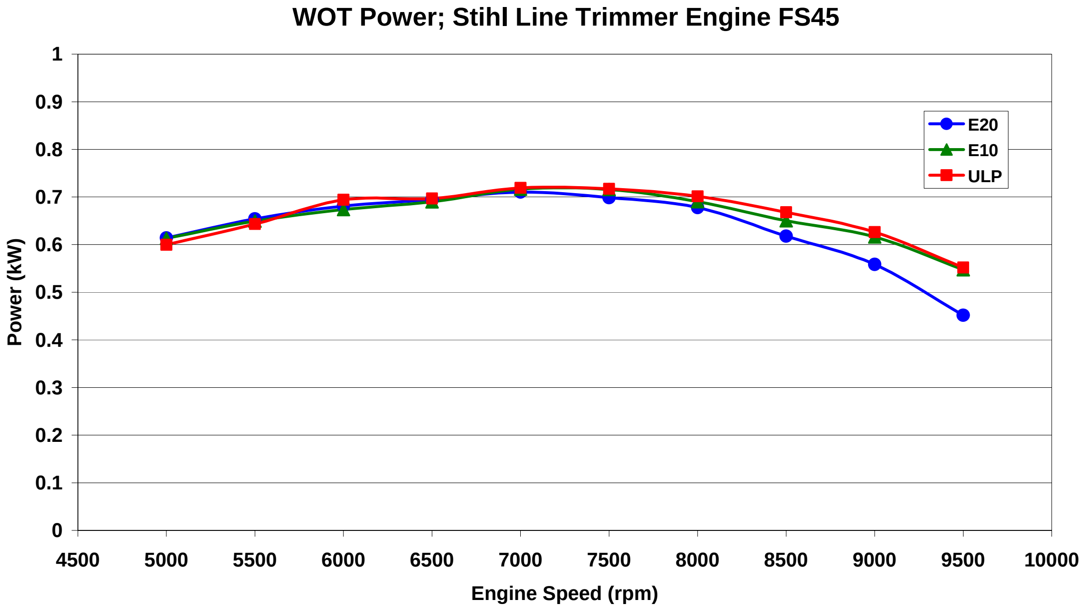


Figure 5.2.2 Utility Engine WOT Power Results

As is evident from Figure 5.2.2, there is little variation resulting from use of the different fuels up to 8000rpm and whilst ULP and E10 perform equally throughout the speed range, the E20 data shows a significant drop in performance at higher speeds. The trend with E20 is outside the variability generally experienced during assessments with this engine and is expected to be a true shift in performance. The power deficit measured with E20 can be attributed to increasing enleanment of the mixture as evidenced by the equivalence ratio decrease for the E20 shown in Figure 5.2.4.

Further test results and charts are contained in the Test Report attached as Appendix B-2.

5.2.1.1.3 Enleanment during Engine Power Test

The theoretical enleanment due to the addition of ethanol in the fuel blend is compared to the measured results at one point in the engine power test in Figure 5.2.3 and shows reasonably good correlation between measured and theoretical equivalence ratios for the E10 fuel blend. However, the correlation is not as good with the E20 blend, with measured results showing more enleanment than expected. This result was opposite to that observed during the emissions testing (conducted at an engine speed of 8300rpm).

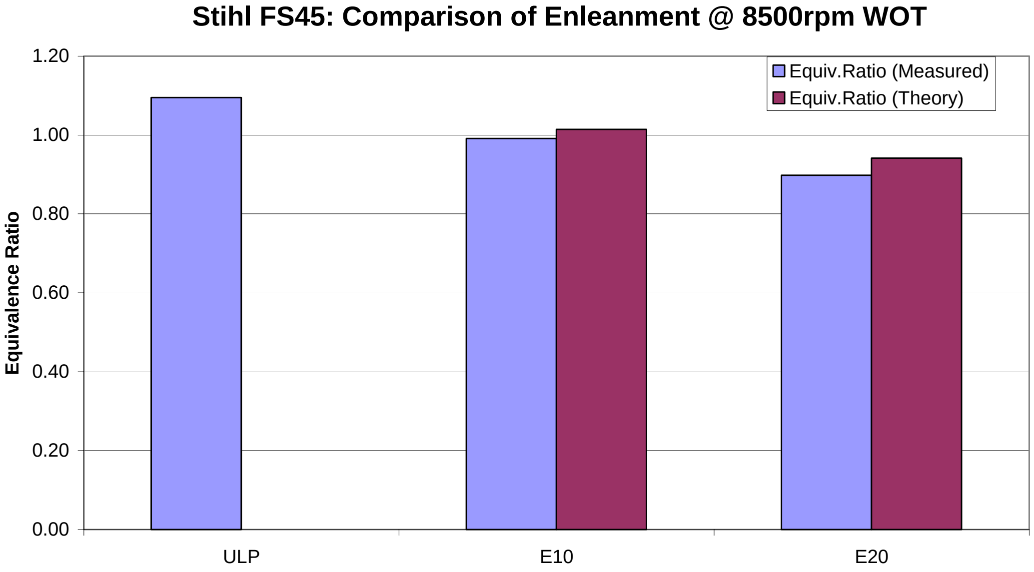


Figure 5.2.3 Utility Engine Enleanment Results – Power Test

Examination of the equivalence ratio throughout the speed range is shown in Figure 5.2.4 below. When operating with E20, the equivalence ratio is seen to be excessively lean for an engine designed to operate as a richer then stoichiometry homogeneously charged combustion engine, and it is that which results in the drop in performance noted. Despite the very lean equivalence ratio, engine operation and run quality was still acceptable.

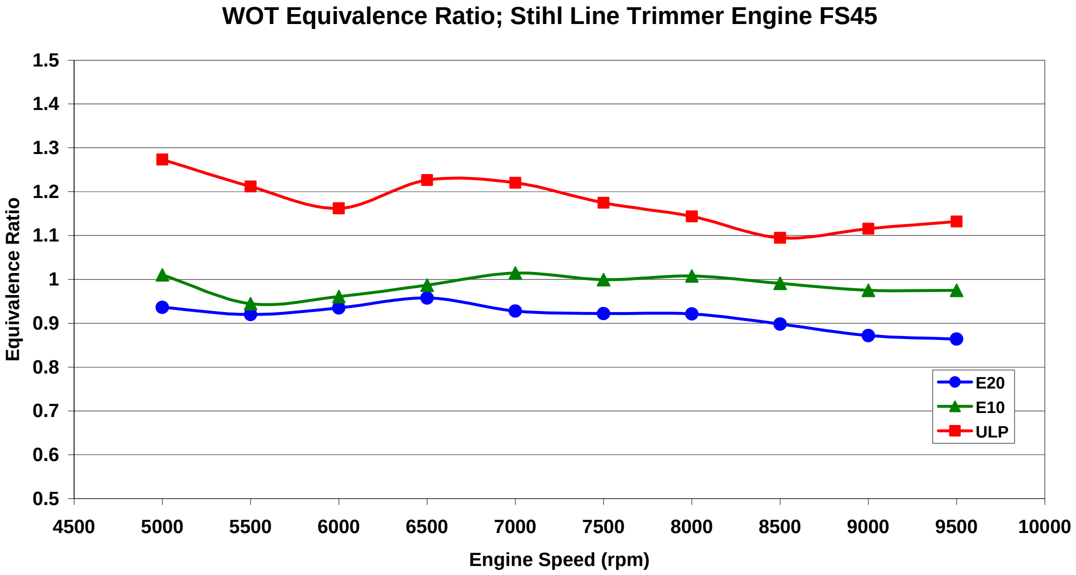


Figure 5.2.4 Utility Engine WOT Equivalence-Ratio Results

Examination of exhaust port gas temperatures highlights that the temperature does increase as a result of the use of ethanol in the fuel blend, however the incremental increase with increasing ethanol proportion is not as clear for the utility engine as it was with the marine engine, see Figure 5.2.5. Based on the data collected, the lack of incremental increase for E20 is most likely due to the equivalence ratio of the mixture falling significantly below 1.0 (a very lean mixture) which can theoretically result in little change or reduction in exhaust gas temperature is sufficient enleanment is encountered. This is due to the excess air effectively absorbing some of the energy released from the combustion event. The resulting exhaust gas temperatures are therefore lower than what would be expected due to slight enleanment from a richer than stoichiometric base condition.

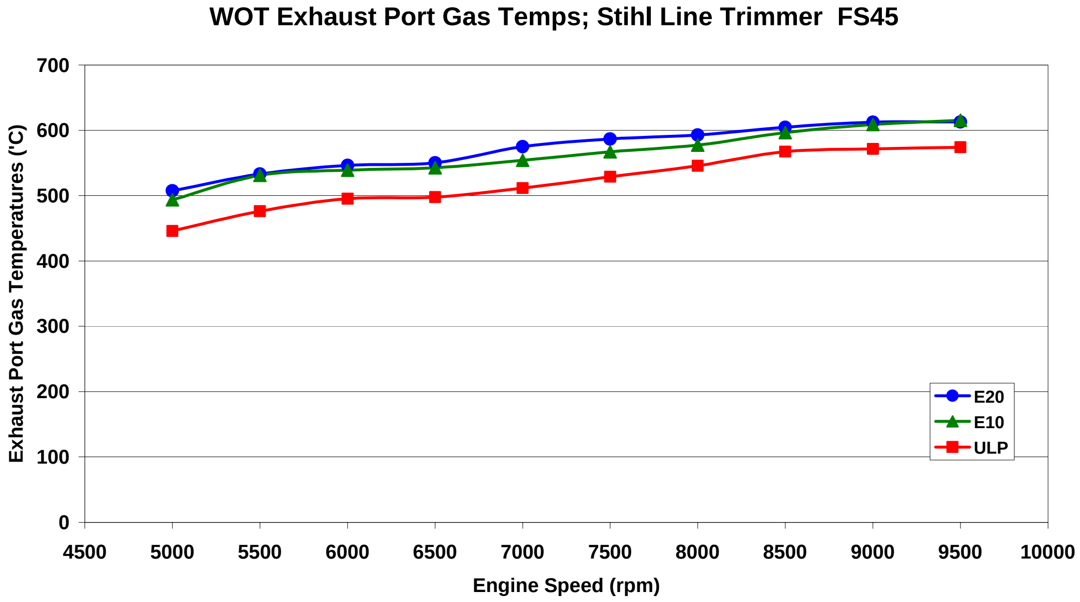


Figure 5.2.5 Utility Engine WOT Exhaust Port Gas Temperatures

5.2.1.1.4 Exhaust Gas Emissions

Exhaust gas emissions tests were conducted in accordance with the 2-point J1088 test for handheld engines, with the exception that only dry sampling of HC and other emissions was used. The consequence of this is that whilst results for the different fuel blends may be compared, the absolute results should not be compared to legislated limits with regard to emissions control.

The two operating points (test modes) are the engines rated speed / load and idle. Results from each test point are aggregated using a weighting factor to produce a composite result. The speed and load set points calculated for the Stihl engine are as summarised in Table 5.2.1 below:

	Mode 1	Mode 2
Speed (rpm)	8300 (rated speed)	2800
Torque (Nm)	0.78	No load
Weighting factor	0.85	0.15

Table 5.2.1 Stihl FS45R J1088 test points

The main testing issue once again was the high variability in engine results with the one fuel type exhibiting scatter which tended to swamp the difference between fuel types, which was the prime aim of the testing program. In fact, the trends for decreasing performance with the E20 blend during the WOT test was contradicted by the test at 8300rpm WOT which showed the engine to produce more power than with ULP. At this speed however the order of change was less than 5%, and for such small engines and dynamometer calibrations, can be considered to be within experimental variability.

The average “Cycle Weighted” results from the J1088 emission tests from the three different fuel blends are shown in Table 5.2.2 below:

Fuel Type	**ULP**	**E10**	**E20**
Ave. Weighted FC (g/kWh)	766	754	756
Ave. Weighted HC (g/kWh)	133	124	122
Ave. Weighted NOx (g/kWh)	0.4	0.7	0.4
Ave. Weighted CO (g/kWh)	442	294	361
Ave. Weighted HC+NOx (g/kWh)	133	125	123

Table 5.2.2 Utility Cycle Weighted Fuel Consumption and Emissions Results

The average results do not reveal any significant trend or conclusion about the effects of operating with ethanol blends. In general terms, most indicators are within the limits of experimental variability. Even closer examination of parameters such as the equivalence ratio failed to reveal a conclusive trend that was dominant over the data obtained for the three fuels tested.

Further test results and charts are contained in the Test Report attached as Appendix B-3.

5.2.1.1.5 Enleanment during Emissions Test

Whilst reasonable correlation between theoretical and measured equivalence ratios is seen in Figure 5.2.6 for E10, measured results for E20 disagree with those measured during the power test, and are in fact richer than theoretical. This variable behaviour highlights the variability in engine performance seen with this small utility engine during the testing.

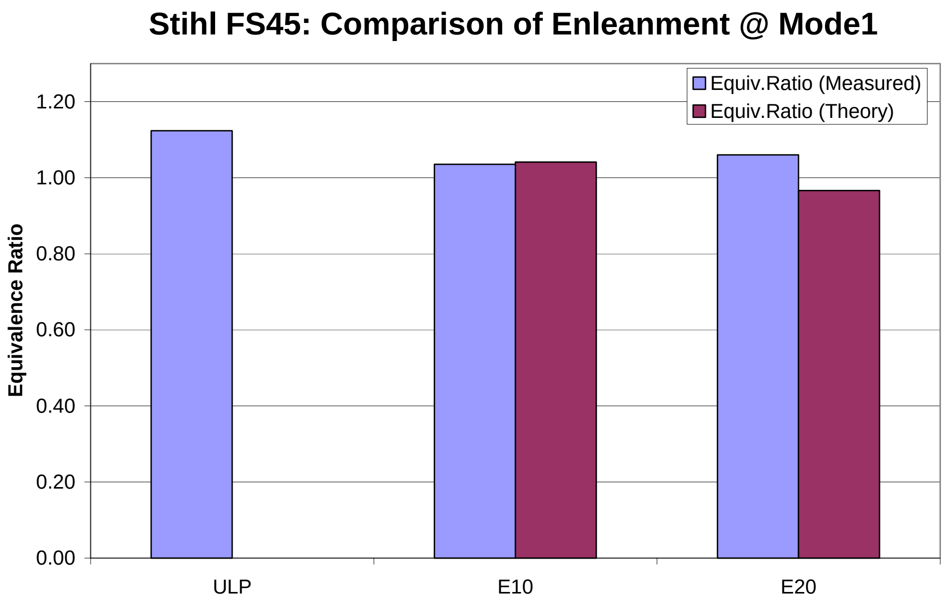


Figure 5.2.6 Utility Engine Enleanment Results – Emissions Test

5.2.1.1.6 Discussion.

It can be concluded for the testing carried out that the variability observed when testing the engine on one fuel was as great as the differences recorded across all three fuel blends. This is the case for the utility engines performance and exhaust gas emissions. At the extremes of the engine operating range, well above the engine's rated speed, only E20 was seen to result in a significant change in performance, that being a reduction in power hypothesised to be attributed to a very lean fuel air mixture as evidenced by the equivalence ratio graph, Figure 5.2.4. This is also substantiated by the exhaust port gas temperature showing the expected increasing trend with E10, but no incremental increase in temperature with the E20 fuel blend.

During testing, there was an occasional inexplicable variation in torque and exhaust gas CO concentration measurement indicating a change in the quantity of fuel metered to the engine by the carburettor, rather than an instrumentation issue. This variation in carburation appears to be more significant than the influence of ethanol in the fuel blend (E10 and E20).

The general calibration philosophy adopted by many utility engine manufacturers is one of calibrating these small engines on the "rich" side, thus building in some tolerance for variability in fuel quality and operating ambient conditions. This "rich" setting normally means the exhaust gas CO concentration is higher than 3% when the engine is operating at WOT conditions.

5.2.1.2 Operability Assessment

A different engine to that used for the dynamometer assessments was used in the assessment of operability. Operability tests were conducted with the engine connected to the complete line trimmer assembly and tested as a product. Were appropriate a portable logging system was used to record engine speed and key temperature parameters. The data logging was complemented by the use of a Digital Storage Oscilloscope. Although the operability assessment is predominantly subjective, the procedures adopted represent industry respected methods.

The start tests conducted at non-ambient conditions were performed using an Environmental Testcell to provide temperature control at both 40°C and 0°C, during hot and cold soak tests respectively. During the hot soak tests, solar heating lamps were additionally used to provide direct heating to the line trimmer engine area.

5.2.1.2.1 Hot Start

Hot start testing of the utility engine was conducted with the engine having been pre-conditioned by operating the engine at it's rated speed for 5 minutes or until temperatures of the exhaust gas, spark plug and the inlet air stabilise prior to entering the Environmental Testcell. The line trimmer was then stopped and placed in the Environmental Testcell that was stabilised at 40°C under the solar heating lamps. The line trimmer was allowed to heat soak for 15 minutes before attempting to start the engine.

The engine started within two pulls for all three fuel blends tested. All starts exhibited a similar flare, but there was some minor variability in the idle following the start. Generally there was the tendency for idle speed to be higher with increasing ethanol content, though in no case was the idle considered objectionable or unacceptable, Table 5.2.3 and Table 5.2.4

	Fuel Type		
Speed Condition	**ULP**	**E10**	**E20**
Flare engine speed (rpm)	7730	7770	7840
Normal idle engine speed (rpm)	3010	3295	3325

Table 5.2.3 Hot Start Flare and Normal Average Idle Engine Speed

	Fuel Type		
Speed Condition	**ULP**	**E10**	**E20**
Flare engine speed fluctuation (rpm)	+/-30	+/-150	+/-130
Normal idle engine speed fluctuation (rpm)	+/-50	+/-75	+/-205

Table 5.2.4 Hot Start Flare and Normal Idle Engine Speed Fluctuation

Further test results and charts are contained in the Test Report attached as Appendix B-4.

5.2.1.2.2 Cold Start

Cold start testing on the utility engine was conducted with the engine having been soaked for a minimum of 8hrs at 0°C in the Environmental Testcell.

The manufacturer's procedure called for 5-pulls in the choked position and up to 10pulls in the un-choked position. The engine started within two pulls in the un-choked position for all three fuel blends tested. To varying degrees, all engines flared to 7000rpm, then dropped to the fast idle speed. Interestingly the engine also fired on the second pull during the choked mode for all fuel types.

Tests with the ethanol blended fuels somewhat improved idle run quality over that with ULP. There was no discernable difference in the performance between E10 and E20, Table 5.2.5 and Table 5.2.6.

	Fuel Type		
Speed Condition	**ULP**	**E10**	**E20**
Flare engine speed (rpm)	4550	6740	5615
Normal idle engine speed (rpm)	3210	2910	3190

Table 5.2.5 Cold Start Flare and Normal Average Idle Engine Speed

	Fuel Type		
Speed Condition	**ULP**	**E10**	**E20**
Flare engine speed fluctuation (rpm)	+/-350	+/-515	+/-1325
Normal idle engine speed fluctuation (rpm)	+/-150	+/-205	+/-180

Table 5.2.6 Cold Start Flare and Normal Idle Engine Speed Fluctuation

Further test results and charts are contained in the Test Report attached as Appendix B-5.

5.2.1.2.3 General Operability

Operability was assessed by examining engine speed data logged for a series of manoeuvring tests. These tests required the engine to be held at constant speed by setting the trimmer line length, then swinging the unit in different directions. The ability to maintain engine speed with minimal fluctuation forms the performance criteria. These tests were performed with the engine following both cold and hot soak tests.

All fuels were able to perform the series of tests without stalling. There was a tendency however for the fuel blends with ethanol to show a greater sensitivity to engine speed fluctuations particularly for manoeuvres in certain rotations. Side to side motion, the most general test case, was satisfactory for all fuel types. The engine speed fluctuation was found to be between two to three hundred rpm, and it is doubtful as to whether this would be discernable to the average operator.

The fuel tank “run-dry” simulation tests showed the engine was able to be started with each fuel type, confirming that this was not an identifiable performance concern.

Further test results and charts are contained in the Test Report attached as Appendix B-6.

5.2.1.2.4 Discussion

Operability as assessed by this series of subjective tests was generally acceptable for all fuel types.

The engine would start within two pulls with all fuel types regardless of hot or cold conditions. Idle quality following the start was in some cases worse with a particular fuel type, but in none of the tests was it characterised as being unacceptable. With a hot start, there was some tendency for increases in idle speed and a loss of smoothness as a result of increases in ethanol content as compared to ULP. With a cold start, the trend was the reverse with ethanol blends improving engine operation compared to ULP.

Operability as assessed by the manoeuvrability tests at different operating speed thresholds identified only that there was a tendency for some engine speed fluctuation to be induced by the swinging motion when operating on ethanol blends. There were no instances however where the manoeuvres led to engine stall.

5.2.2 Engine Durability

All three engines completed the 100hour test cycle with no failures recorded.

The details from the pre and post strip downs are contained in the Engine Strip Reports attached as an Appendix.

Test Report B-7 attached examines the data in the individual Strip Reports and provides details such as calculation of wear and observations.

From the data logged during the durability cycle it is clear that all three engines completed the same duty cycle and test hours and reached similar speeds during the WOT phase, see Figure 5.2.7.

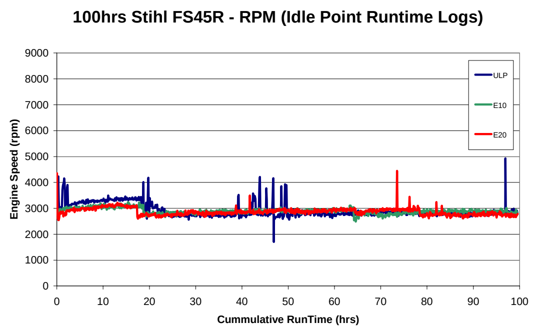
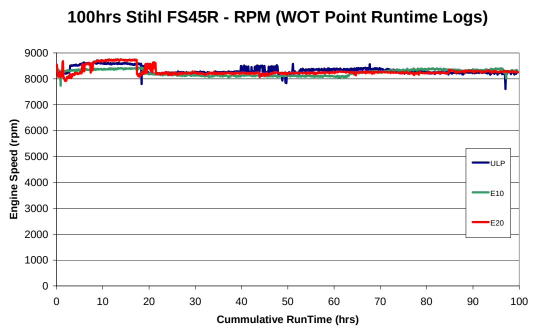
Idle Speed log points	**WOT Log Points**
	

Figure 5.2.7 Utility Engine 100hr Test Log

There are two points of significant note from the above data.

- During the first day of running, there is some variation in running speed noted. This variation is believed to be due to wearing of the flex drive to the line trimming head. Once worn in, and the line length reset, no further variation was seen between engines over the remainder of the test period

- Occasional spiking in the idle speed logged for the engines is noted. This is most likely due to the data logging occurring during a very short idle period in the test phase. With only 54 seconds allowed for idle, it is highly probable that some of the data recording period may have occurred whilst the engine was still transitioning from the WOT set point. This is only of minor consequence, as the data log confirms all engines followed the same test cycle.

5.2.2.1 Base Engine Wear

Measurements were made of all key base engine components, and wear calculated as the change from pre to post dimensions. The wear for all three engines was compared and found to be within acceptable limits based on the data in Test Report B-7. A complete listing of measured parameters is included as an attachment to Test Report B-7, but a summary of this data for all three fuels is provided in Table 5.2.7.

Component	Wear
Piston skirt and cylinder bore	0-25um
Piston pin and pin bore	0-3um
Piston ring gap and groove clearance	No change

Table 5.2.7 Summary of Utility Engine Wear

There was no evidence of there being specific base engine wear that was associated with a particular fuel type.

5.2.2.2 Engine Deposits

Deposit formation was assessed visually and recorded using digital photography.

General deposit formation for engines operating on ULP and E10 fuel is acceptable. The engine run on E20 fuel had carbon blockage of the exhaust blow down port as shown in Figure 5.2.8. This blockage could lead to changes in performance and noise, and to longer-term durability issues. However, no specific performance assessments were made to quantify the impact these changes may have already had, and as all engines reached similar WOT speeds, the power levels are expected to have remained similar.

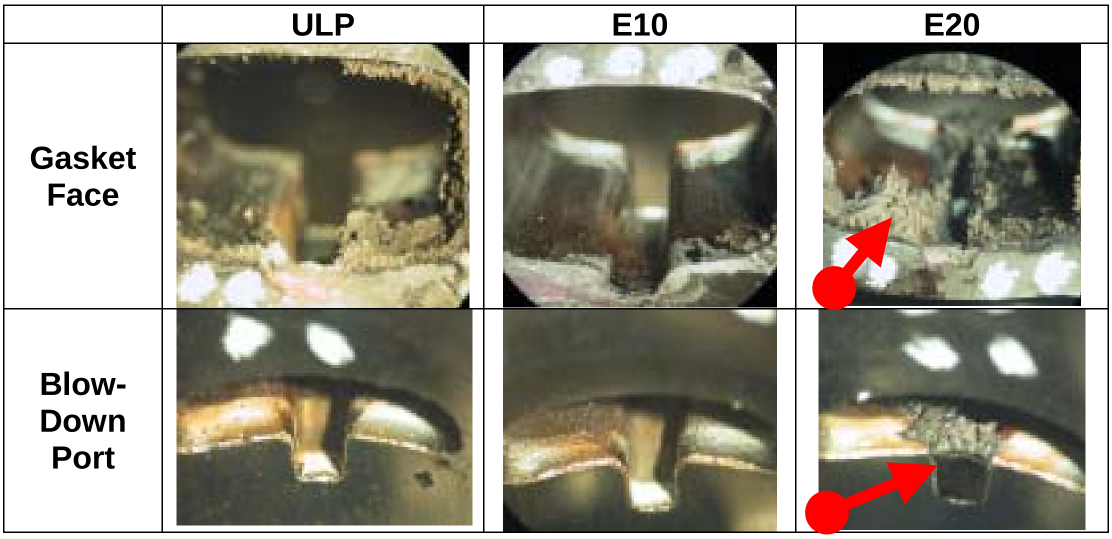


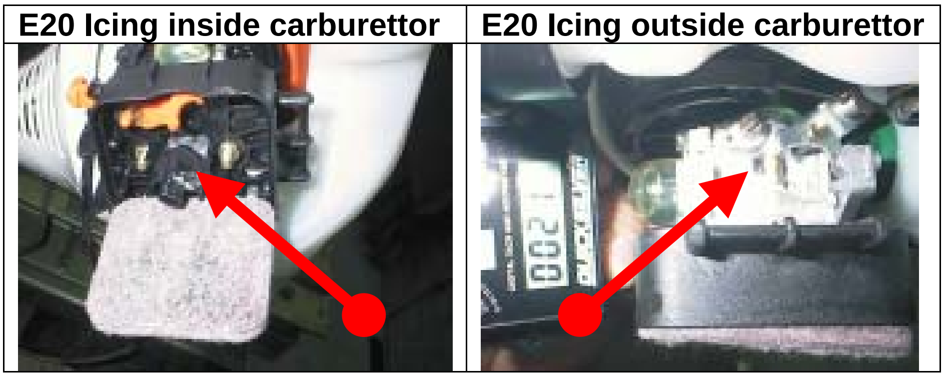
Figure 5.2.8 Utility Engine Exhaust Port Deposit Condition

Examination of the sparkplug deposits show these to be progressively lighter in colour as the proportion of ethanol in the fuel blend increases from ULP to E10 to E20, however were no problems identified associated with this. The general observation would be that lighter plug colour infers hotter operation.

5.2.2.3 Fuel System Durability

No specific fuel system durability problems leading to loss of engine function were found, however, the following was identified.

The engine operating with E20 fuel was observed to undergo fuel system icing (see Figure 5.2.9) in humid ambient conditions leading to high levels of emulsion formation. No performance measurements were made to record whether this resulted in a change to performance, but from the examination of the runtime data there was no sudden reduction in WOT speed logged during the duration of the 100hr test, concluding that the emulsion has little or no effect on the engine performance.


E20 Icing inside carburettor

E20 Icing outside carburettor

Figure 5.2.9 Utility Engine - Icing formation on E20 engine

The carburettor lower diaphragm showed signs of swelling and blistering that, although negligible for ULP, was slight for E10 and severe for E20 fuels (see Figure 5.2.10). This has the potential in the longer term to lead to loss of internal or external sealing which in turn could lead to fuel leakage, engine damage and engine stoppage. However, such terminal failure did not result with the E10 and E20 test engines.

ULP	E10	E20
		

Figure 5.2.10 Utility Engine - Carburettor Lower Diaphragm

5.2.2.4 Fuel System Deposits

Fuel system deposit formation on all 3 engines after completion of the durability test was acceptable. There was no evidence of any effects from the icing/emulsion condition noted during some phases of the test program.

5.2.2.5 Discussion

All three engines completed the required 100hr durability test cycle with the respective fuel blend. All were seen to be performing comparably at the end of the test period as could be judged by examining their ability to reach comparable WOT speeds.

Formal assessments of component wear and visual inspection of components found that:

- Wear was within acceptable limits for all three engines with no specific bias to one fuel blend over another
- Engine deposits were acceptable for ULP and E10 engines, but the engine run on E20 fuel had carbon blockage of the exhaust blow down port and elevated carbon deposits in the exhaust port proper.
- Fuel system durability was highlighted by evidence of the carburettor lower diaphragm swelling and blistering. This was negligible for ULP, slight for E10 and severe for E20 fuels. This has the potential in the longer term lead to loss of internal or external sealing which in turn could lead to fuel leakage, engine damage and engine stoppage
- During testing, the engine run on E20 fuel was observed to cause fuel system icing in humid ambient conditions leading to high levels of emulsion formation. Based on the data recorded from the durability cycle, it can be concluded that the emulsion has little or no effect on the engine performance or durability.

It should be noted that the above summary is based on a sample of one engine per fuel type, and as a consequence, the drawing of any specific conclusions about trends as a function of fuel type relies strongly on the assumption that the individual base engines would have performed equally had they be tested on the same fuel type.

The higher carbon deposit formation found for the engine operating on the E20 fuel blend has been identified as having the potential to lead to longer-term durability issues. Deposit formations differ substantially to the ULP and E10 case in the region of the blow down port where it is completely filled in the E20 case and totally clear in both the ULP and E10 case. The general level of deposits in the exhaust port near the gasket face is also increased compared to the ULP and E10 cases. The issue of longer term durability is related to the increased potential for the exhaust port deposits to dislodge, get carried into the engine and come into contact with the highly finished bearing surfaces, sealing areas and the piston and piston ring contact area with the cylinder bore, thereby increasing the wear rates of these components as well as leading to premature failure of these components.

6 Materials Compatibility Test Activity

6.1 Overview

This activity is focussed on conducting materials / component compatibility testing following as closely as possible the relevant SAE standards J1748 (13) (polymeric material) and J1747 (12) (metallic material). SAE standard J1681 (11) was followed as closely as possible for defining the test fluids utilised for material / component immersion the testing.

The testing and experimental design is not an attempt to fulfil the requirements for material qualification, actual product or process validation for the materials or components. The experiments and testing are in fact designed to highlight any non-compatibility between a material or component and the E20 blend fuel.

6.2 Component Test Preparation

6.2.1 Test Fuel

As proposed in the tender submission, testing is occurring with 0% ethanol and 20% ethanol/gasoline fuel blends. The fuel blends containing the 20% ethanol will be based on standard pump fuels plus 1% corrosive water, similar to that specified in (11).

For evaluation of components from marine and utility engines, the sample fuels required for immersion of each test piece, are:

- Standard unleaded petrol (WA pump gasoline)
- Standard unleaded petrol with 20% ethanol and 1 % corrosive water.

As the marine and utility engines both operate using a pre-mix of fuel and oil, the above two fuels are mixed at a rate 50:1 with Stihl brand 2 stroke engine oil. The same pre-mix is used for components from both the marine and utility engine as a means of consolidating the number of fuel mixes supported. The choice of oil brand is not expected to have an appreciable impact on the results of the material compatibility tests.

6.2.2 Test Temperatures

The specified temperatures for material testing are as follows:

- Metals at 45+/-2^{o}C
- Elastomers at 55+/-2^{o}C
- Plastics at 55+/-2^{o}C

Fuel sample containers are normally held in a temperature-controlled oven. Due to safety issues identified with the ovens and also due to the number of containers (120) required for this program, testing is being conducted in a fire protected environmental engine test cell. In order to facilitate testing of all samples at the same time, the test temperature has been standardised to 55+-2^{o}C. This will not adversely affect the validity of findings for the metals testing. The higher temperature is considered to be more closely aligned with the normal operating temperature of many of the components under test.

6.2.3 Test Containers

The containers for this testing are specified by the SAE standards. The containers are made of high density polyethylene, with a minimum rated burst pressure of 202.7 kPa and a volume of one litre. These unique requirements have necessitated procurement from the USA. Delay in the supply of these containers was the primary reason for delaying the test program until late-December 2002.

6.2.4 Facilities

The environmental test cell and adjacent anteroom have been configured to enable testing to be undertaken in an effective and safe manner.

- The test cell is controlled to 55+/-2^{o}C (SAE standard for material testing) and the anteroom is controlled to 23+/-2^{o}C (SAE standard for component measurement). Temperature control of the test cell and anteroom has been validated over an extended period.
- The anteroom has been modified to incorporate a bench with fume hood and extraction system (see Figure 6.2.1). This bench is used for sample preparation and condition assessment throughout the test period.
- Fuel drums (with taps) and racks have been fitted to the bench to facilitate replenishment of each fuel type. A waste fuel drum on wheels is located next to the bench.

Anteroom – fume hood, fuels and scales

Container Racks stored in Heated Room

Figure 6.2.1 Materials Compatibility Test Facilities

6.2.5 Procedures

Procedures covering test method, facilities control and safety have been documented.

6.2.6 Sample Preparation

As both the marine and utility engine are of a two stroke design, major engine components which may come into contact with fuel, not just those associated with the fuel system, have to be subjected to the tests. This includes a significant number of metal and non-metal parts downstream of the carburettor. Some test pieces have been cut from the larger items, for example fuel tank test pieces. The metal components downstream of the carburettor have not been included for immersion in neat ULP as these components are very unlikely to present with no issue and from a logistical point of view to keep the samples to a reasonable number.

6.3 Test Status

The progress to date has been delayed due to a number of logistical concerns that have only recently been resolved. All facilities preparations have now been completed, test procedures documented and component samples purchased and prepared (see Figure 6.3.1).

Figure 6.3.1 Test Samples in Containers

For the Mercury 15hp small outboard engine 98 parts in 42 test containers have begun their test and are currently being soaked. At the time of writing this report, the accumulated immersion time for the components was 482 hours.

For the Stihl FS45R line trimmer engine 56parts in 31 test containers have begun their test and are currently being soaked. At the time of writing this report, the accumulated immersion time for the components was 640 hours.

The above tests on the non-automotive components were started mid-December. The test duration is three months, primarily driven by the necessary time to complete the corrosion tests (2000 hours). Accordingly, the revised completion date for this activity is planned for mid-April 2003.

6.4 Experimental Data

With the immersed samples having reached a significant number of hours, some of the samples have started to demonstrate some significant incompatibility issues when comparing between the neat ULP and E20 soaked samples. The information presented here does not include quantitative measurements of the changes in terms of the following list.

- Weight change
- Dimensional analysis
- Hardness measurement (plastics only)
- Photographic evidence.

The information is a preliminary review based on visual inspections of the components in terms of distortion as either enlargement or loss of shape, discolouration and evidence of corrosion.

6.4.1 Mercury 15hp Engine Preliminary Inspection Results

A listing of the components presenting a clear visual incompatibility with the E20 test fuel mix is identified. These components, unless specified are not tested with the ULP test fuel, have shown no visual incompatibility with the ULP test fuel.

The following metal base engine components have been identified with evidence of corrosion:

- Crankshaft seal, rust on metal housing.
- Cylinder liner, rust spots identified on surface that is in sealing contact with piston rings and contact with piston.

Polymeric components identified as presenting with distortion are:

- Fuel delivery hose - plastic insert is distorted.
- Fuel primer bulb - presented with enlargement.
- Fuel sight glass (a plastic) - exhibited discolouration of the glass.

The tarnishing of all the brass fuel system components immersed in the E20 test fuel indicates that an oxidation process is occurring.

A carburettor diaphragm attached to a gasket with most likely a light adhesive has started to separate from the gasket.

6.4.2 Stihl FS45R Engine Preliminary Inspection Results

A listing of the components presenting a clear visual incompatibility with the E20 test fuel mix is identified. These components, unless specified or not tested with the ULP test fuel, have shown no visual incompatibility with the ULP test fuel.

The following metal base engine components have been identified with evidence of corrosion:

- Connecting rod, rust on surfaces.
- Exhaust box, surface finish degrading.

Polymeric components identified as presenting with distortion are:

- Fuel primer bulb, enlarged by approximately 50%.
- Crankshaft seal, exhibited enlargement and loss of annular shape.

The tarnishing of all the brass fuel system components immersed in the E20 test fuel indicates that an oxidation process is occurring.

A carburettor diaphragm attached to a gasket with most likely a light adhesive has started to separate from the gasket. The same component immersed in the ULP test fuel has shown the same separation activity.

6.4.3 Discussion

The following discussion refers to the potential issues arising should the identified incompatibility occur in the actual engine. The objective of routine materials compatibility testing is to effectively accelerate processes leading to incompatibility to ensure corrective actions can be made before releasing the product to the customer.

The identified corrosion of the internal base engine components of both the engines is of concern, as there is potential for the oxide to dislodge and become trapped in between moving surfaces such as rotating bearing areas, seal running surfaces and the piston and cylinder walls. This situation would most likely result in accelerated wear of these surfaces. The potential exists, depending on the severity of the oxidation and the actual final location of the dislodged oxide, to cause engine failure. The corrosion potential exists in normal application due to these types of engine application products to be idle for long periods of non use. Upon stopping the engine, fuel remains in the engine crankcase and in the carburettor providing the potential for corrosion for the E20 fuel blend. The corrosion of the exhaust box of the Stihl engine can be viewed as presenting little issue apart from the potential of an earlier then expected deterioration of the finish of the component.

The identified distortion of the various fuel system and base engine polymeric components is also of concern. In general, enlargement or swelling of these components is accompanied by softening thereby increasing the probability of mechanical damage. Should mechanical damage occur, fuel leakage would follow. The fuel primer bulbs for both engines suffered enlargement when immersed in the E20 test fuel blend, while no visible change was noted for the same components immersed in the ULP test fuel.

The seal from the Stihl engine is utilised to maintain a fluid tight seal between the engines crankcase and the atmosphere. In particular the seal contains a circular lip that seals with a highly finished surface on the crankshaft facilitating the sealing function. Should the seal distort in the manner identified through the immersion testing in the E20 mix, it is highly likely that the fluid tight seal would be lost allowing fluids to transfer between the engine crankcase and the atmosphere. This situation would result in reduced engine power and possibly loss of engine function. The potential also exists for fuel to leak out of the engine crankcase and into the atmosphere. A further possibility is for the seal to be mechanically damaged by rotating engine components due to the enlargement. This may be followed by loss of engine function or further engine damage. The potential for fuel leakage to the atmosphere also exists. The same seal tested in ULP showed no change in visible appearance.

The plastic insert in the fuel delivery hose of the Mercury engine fuel system was identified as distorting after immersed in the E20 test fuel. Though the level of distortion of the plastic insert was not measured, the potential for fuel leakage due to a potential loss of sealing between the hose and the insert exists. The same component immersed in the ULP test fuel showed no visible change of appearance.

For both engines, all brass fuel system components have been tarnished from the immersion in the E20 test fuel indicating that an oxidation process is occurring. The oxidation of many of the brass components is in general not a significant issue. However oxidation of brass fuel and air metering jets or fuel control devices in the engine carburettor is regarded as a significant issue. These components generally are manufactured within small tolerances to ensure correct metering of air and metering or control of fuel. Should oxidation occur the intended nominal air metering and fuel metering or control has the potential to be lost, resulting in potential degradation or loss of engine function.

The fuel level sight glass of the Mercury product is manufactured from a plastic material. Discolouration of the sight glass may indicates loss of mechanical strength as in general; a change of appearance of polymeric materials is an indicator that the mechanical properties are degrading. The hardness property was not measured during the preliminary inspection. The same component immersed in ULP did not display any visible change in appearance.

The separation of the carburettor diaphragm and gasket is not considered a significant issue, as the combination of the two components is likely to facilitate assembly of the carburettor, and once in position, the clamping force provided by the fasteners will locate and secure both components.

7 Discussion and Conclusions.

This report summarises the results on the performance and durability evaluations conducted on two types of non-automotive engines with one gasoline only and two blends of ethanol and gasoline fuels, E10 and E20. Material compatibility testing has also been initiated, with only preliminary results reported as the tests are currently still ongoing and have not yet been completed due to logistical issues related to receiving suitable containers for immersion of the test samples.

The engines tested represent two broad categories; marine engines and small utility engines. The Mercury Marine 15hp 2-stroke outboard engine was selected as being representative of the marine engine category. The Stihl FS45R line trimmer was selected as being representative of the small utility engine category.

7.1 Performance and Emissions Assessment

The performance testing of these engines included power and emissions assessment, operability and starting performance tested under hot and cold conditions. Both engines operated satisfactorily with all three fuel blends tested (ULP, E10 and E20) though there were some differences in performance that may be noted by a critical observer in special situations. A summary of the findings is contained in Table 7.1.1.

Engine performance was found to be generally comparable for all fuel types, with the marine and utility engines generally exhibiting similar trends. Of most notable concern are:

For the marine engine:

- increasing the ethanol content in the fuel blend increases the tendency for misfire during some operating conditions including extended trolling and excessive engine tilt
- when operating on E20, the engine would stall when WOT acceleration was demanded following an extended trolling test. The engine would however restart and run following the stall

For the utility engine:

- some engine speed fluctuation during operability manoeuvres was present when using ethanol blended fuels

Some of these effects are likely to be a result of the leaner operation induced by the addition of ethanol into the fuel blend, with the test data gathered confirming this enleanment. Other causes may include the design and hot fuel handling capability of a particular system, resultant from a fuel volatility issue. Generally speaking, these marine and small utility engines are factory calibrated sufficiently rich to cope with some in-field enleanment, the level to which is product and manufacturer dependent with no manufacturers recommending the engines be operated with more then a 10% ethanol gasoline blend.

Although there is no exhaust gas emissions legislation for Australia, for the non-automotive engines tested, the general behaviour of the engines exhaust gas emissions is presented. In general the emissions of HC’s and CO reduced while the NOx increased with increasing ethanol content of the fuel. This trend complements the expected and measured enleanment provided by the increasing ethanol content.

During the testing, engine temperatures were recorded to understand the effects of the ethanol fuel blends on engine operating temperatures. Exhaust gas temperatures were recorded and a trend of increasing temperature with increasing ethanol percentage in the fuel was found as expected, due to the fuel mixture strength (equivalence ratio) reducing with increasing ethanol content. The Stihl engine during the performance testing did not show an incremental increase in exhaust gas temperatures for the E20 blend compared to the E10.

	Marine Engine	**Utility Engine**
Power	Impact: • E20 has more power throughout range, up to 3% • E20 too lean to run stably at low speed	Impact: • E20 performance drop at higher than rated speed, up to 18%
Enleanment	Impact: • E10 leaner than ULP • E20 leaner than E10	Impact: • E10 leaner than ULP • E20 leaner than E10
Emissions	Impact: • CO reduces by up to 45% with E20. • NOx increases by up to 91% with E20. • HC's decrease by up to 5.9% with E10	Impact: • CO reduces by up to 33% with E10 • NOx increases by up to 75% with E10 • HC's decrease by up to 6.7% with E10
Engine Temperature	Exhaust Gas Temperature • E10 increased over ULP by up to 15°C. • E20 increased over ULP by up to 27°C	Exhaust Gas Temperature • E10 increased over ULP by up to 28 °C • E20 similar to E10
Cold Startability	Comparable: • Idle better with ethanol fuel blends	Comparable: • Idle better with ethanol fuel blends
Hot Startability	Comparable: • Idle quality better with ULP, ok with E10 • Increased idle speed with increased ethanol content	Comparable: • Idle quality better with ULP, ok with E10 • Increased idle speed with increased ethanol content
General Operability	Impact: • Increasing tendency for misfire with extended trolling, excessive tilt • Engine stalls on acceleration after extended trolling	Comparable, except: • Trend with increasing ethanol for slight engine speed fluctuation 200 – 300 rpm during certain standard test manoeuvres.

Table 7.1.1 Summary of Performance Assessments

7.2 Durability Assessment

Durability assessments were performed by testing a total of three engines, one engine for each fuel blend. Both the marine and utility engine test cycles consisted of alternating periods of WOT and idle operation. All engines completed the test cycles and were assessed as performing comparably at the end of their respective tests. A summary of the findings is contained in Table 7.2.1.

Although none of the fuel blends caused operational problems or discernable base engine wear, the use of E20 fuel raised concerns with regard to deposit formation and material compatibility, specifically:

- Exhaust port carbon deposits (marine and utility engine) and blockage of the exhaust blow-down passage (utility engine)
- Increased piston top ring land deposits and increasing evidence of blow-by (marine engine)
- Severe blistering and swelling of elastomer components - lower carburettor diaphragm (utility engine). It should be noted that the E10 fuel also caused an increased level of blistering and swelling of this component in comparison to the ULP fuel.

It should be re-iterated that these results are based on a sample of one engine per fuel type, and as a consequence, the drawing of any specific conclusions about trends as a function of fuel type relies strongly on the assumption that the individual base engines would have performed equally had they be tested on the same fuel type.

Table 7.2.1 Summary of Durability Assessments

	Marine Engine	**Utility Engine**
Performance	Comparable, all engines ran to similar WOT speed at the end of the 300hr test	Comparable, all engines ran to similar WOT speed at the end of the 100hr test
Base Engine Wear	Comparable, no trends with regard to fuel type	Comparable, no trends with regard to fuel type
Engine Deposits	Impact: • Marginally more carbon in the exhaust port with E20 • Trend with increasing ethanol for more carbon on piston top land ring and evidence of increasing blow-by	Impact: • Excessive carbon deposits on exhaust face and blow-down passage with E20 • Trend with increasing ethanol for spark plug lighter deposit inferring hotter operation
Fuel System Durability	Comparable	Impact: • Tendency for icing during testing with E20 • Carburettor lower diaphragm blister and swell with E10. Severe with E20.
Fuel System Deposits	Comparable	Comparable

7.3 Materials Compatibility Preliminary Assessment

Preliminary data shows that the E20 test fuel is incompatible with both base engine components and with fuel system components utilised in the Mercury outboard and the Stihl line trimmer engine. These findings are based on a visual inspection of the components after over 480 hours of immersion time. The fuel system components, when immersed in the ULP test fuel and subsequent visual inspection after the same immersion period, did not show any visible evidence of incompatibility with the ULP test fuel.

A summary of findings is as follows, and unless stated the components did not show any visible appearance of incompatibility with the ULP test fluid.
Metal engine components.

- Mercury Crankshaft seal displayed corrosion on the metal support.
- Mercury cylinder liner, corrosion spots identified on the sealing contact with the piston rings and contact with the piston.
- Stihl connecting rod, corrosion identified on surfaces.
- Stihl exhaust box, corrosion identified on surface.

Polymeric components.

- Mercury fuel delivery hose, plastic insert identified as distorted.
- Mercury fuel primer bulb, identified as enlarged.
- Mercury fuel level sight glass, identified as discoloured.

- Stihl fuel primer bulb, identified as enlarged by approximately 50%.
- Stihl crankshaft seal, identified as enlarged and losing annular shape.

Brass fuel system components.

- All brass fuel system components were identified as tarnished indicating an oxidation process is occurring.

Others.

- A carburettor diaphragm attached to a gasket with most likely a light adhesive was identified as starting to separate for both the Stihl and Mercury engines. With the Stihl engine component, the same activity was identified with immersion in the ULP test fluid.

7.4 Conclusions

Based on the outcome of the testing undertaken within the program of work designed to uncover and confirm the potential impacts of both a 10% and 20% by volume ethanol and gasoline fuel blend on the non-automotive gasoline engine population, the following conclusions can be drawn.

In general there is little concern related to the impact of the E10 blend fuel.

- Performance testing outcomes indicated that there was comparable performance measured and observed when operating the engines on the E10 blend fuel.
- Durability testing revealed that there was two impacts of significance, the slight swelling and blistering of the Stihl engines carburettor lower diaphragm and slight increase in the build up of carbon deposits in the top piston ring groove of the piston when compared with the ULP outcome.

Engineering judgement suggests that none of these impacts are reason for concern.

A number of substantial impacts have been identified through the testing with the E20 blend fuel. These concerns are outlined below.

- Performance evaluation:
    - Exhaust gas temperature has been shown to increase by a significant margin over the ULP baseline leading to potential long-term durability problems, especially with high performance engines.
    - The Mercury engine was found to stall upon WOT acceleration demand after operating the engine in a trolling test, the trolling test simulates low in gear engine operation for an extended period. It was however possible to immediately restart and operate the engine.
- Durability testing:
    - Increasing exhaust port deposits on both engines with the Stihl engine presenting with the exhaust blow-down port blocked completely. This can ultimately lead to longer term durability issues related to the increased potential for the exhaust port

    deposits to dislodge, get carried into the engine thereby increasing wear rates as well as leading to premature failure of the engine components.
  - The Mercury engine was found to have increased top piston ring groove carbon deposits and evidence of combustion gas blow-by on both pistons. This result has been found to be a pre-cursor to piston scuffing and subsequent major engine damage, and therefore indicates the potential for a longer-term durability concern.
  - The Stihl engine carburettor diaphragm was found to suffer severe distortion and blistering. This has the potential to result in loss of internal and external sealing which may in turn lead to fuel leakage. This result is considered unacceptable as it clearly indicates that the diaphragm material is not compatible with the E20 blend fuel.

- Materials compatibility testing:
  - Metallic base engine components have exhibited corrosion of engine parts that are in contact with fuel.
    - The crankshaft seal of the Mercury engine contained rust on the metal housing.
    - The cylinder liner of the Mercury engine contained rust on the sealing surface.
    - The connecting rod of the Stihl engine contained rust on surfaces.
    - All these occurrences are considered as a concern as the potential exists for the oxide to dislodge and become trapped in between moving engine components. This situation would most likely result in accelerated wear of these components surfaces. The potential exists, depending on the severity of the oxidation and the actual final location of the dislodged oxide, to cause engine failure.
  - All the brass fuel system components were tarnished indicating an oxidation process is occurring.
    - This is considered as a concern since oxidation of brass fuel and air metering jets or fuel control devices in the engine carburettor has the potential to lead to the loss of the intended nominal air metering and fuel metering or control resulting in potential degradation or loss of engine function.

  - Polymeric materials were found to have significant changes on appearance due to contact with E20 fuel. The following impacts revealed from the testing are considered to be unacceptable have the potential to result in fuel leakage.
    - Fuel delivery hose of the Mercury engine has a plastic insert that was identified as distorted.

- Fuel primer bulb of both the engines was identified as enlarged with the Stihl primer bulb enlarging by approximately 50%.
- The Stihl engine crankshaft seal was identified as exhibiting enlargement along with loss of annular shape.
- The fuel sight glass of the Mercury fuel tank was identified as exhibiting discolouration.

As the materials compatibility testing is ongoing, no invasive testing has yet been performed. These tests will be performed at the conclusion of the compatibility testing (including hardness tests and weight change etc) and will provide a more quantitative assessment of the effects to compliment the qualitative assessments presented to date. It is planned that this will be complete by mid-April 2003.

8 References.

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13. SAE Recommended Practice, Jan 98. "Methods for Determining Physical Properties of Polymeric Materials Exposed to Gasoline/Oxygenate Fuel Mixtures" SAE J1748.

9 Acronyms

AFR	Air Fuel Ratio
A/F ratio	Air/Fuel Ratio
CO	Carbon Monoxide
EA	Environment Australia
E10	Gasoline blended with 10 % Ethanol
E20	Gasoline blended with 20 % Ethanol
FMEA	Failure Mode Effect Analysis
HC	Hydrocarbon
MSDS	Material Safety Data Sheet
NOx	Nitrogen Oxides
ULP	Unleaded Petrol
USA	United States of America
WOT	Wide Open Throttle