THE PERFORMANCE OF A PETROL ENGINE MODIFIED TO OPERATE ON PURE ETHANOL

By E. Meyer

South African Sugar Association Experiment Station, Mount Edgecombe 4300 South Africa

Abstract

The modification of a petrol engine for use with ethanol was done to gain experience in the use of ethanol as an alternative automotive fuel. The modifications that were necessary for a 2ℓ petrol engine to operate on hydrous ethanol are described. The performance, engine wear patterns and fuel consumption of the vehicle were monitored throughout the test period which covered 49 000 km and this paper discusses the problems and conclusions associated with operating a converted spark ignition engine converted to use pure ethanol.

Introduction

A new Ford Cortina 2ℓ (OHC) purchased by the South African Sugar Association Experiment Station was converted to operate on ethanol (4% water) by the Energy Research Institute at the University of Cape Town. The testing of the engine was initially conducted at the Institute and the engine was then installed in the vehicle which was shipped to Durban in 1982 for a long term evaluation.

During the four-year testing period which ended in 1985, the vehicle completed 49 000 km and was used by various members of staff. The use of the vehicle was restricted to the Natal coastal regions. Regular cleaning of fuel passages and adjustment of valve clearances were necessary to maintain a smooth running of the engine. When correctly tuned, the overall performance was satisfactory and the average driver would not be able to discriminate between this vehicle and a standard 2ℓ petrol model. The project has been terminated and the engine dismantled.

Modifications made to the Vehicle

Certain modifications to a standard spark ignition engine were essential for hydrated ethanol to be used as a fuel because the physical and chemical properties of ethanol differ from those of petrol (Table 1). Because of the differences, certain modifications were carried out. (A. Yates: Laboratory testing and road evaluation of a Ford Cortina 2ℓ OHC converted to operate on pure ethanol. Unpublished report). Ethanol has a higher octane rating than regular petrol so it was necessary to increase the compression ratio to improve fuel consumption. The compression ratio was raised from 9,2:1 to 10,6:1 by reducing the volume of the combustion chamber. This was accomplished by skimming 1,1 mm off the cylinder head.

TABLE 1

Properties of hydrated ethanol compared with petrol

Properties	Ethanol	Regular petrol	Premium petrol
Water content (WT%)	6	—	—
Density at 15° (g cm$^{3-1}$)	0,81	0,73	0,74
Boiling temperature (°C)	78	33 to 190	33 to 190
Heating value (kJ kg^{-1})	29 684	47 360	47 080
Latent heat of vaporisation (kJ kg^{-1})	840	320	320
Stoichiometric air-fuel	9,0	14,0	14,0
Researched octane number (RON)	100	93	98

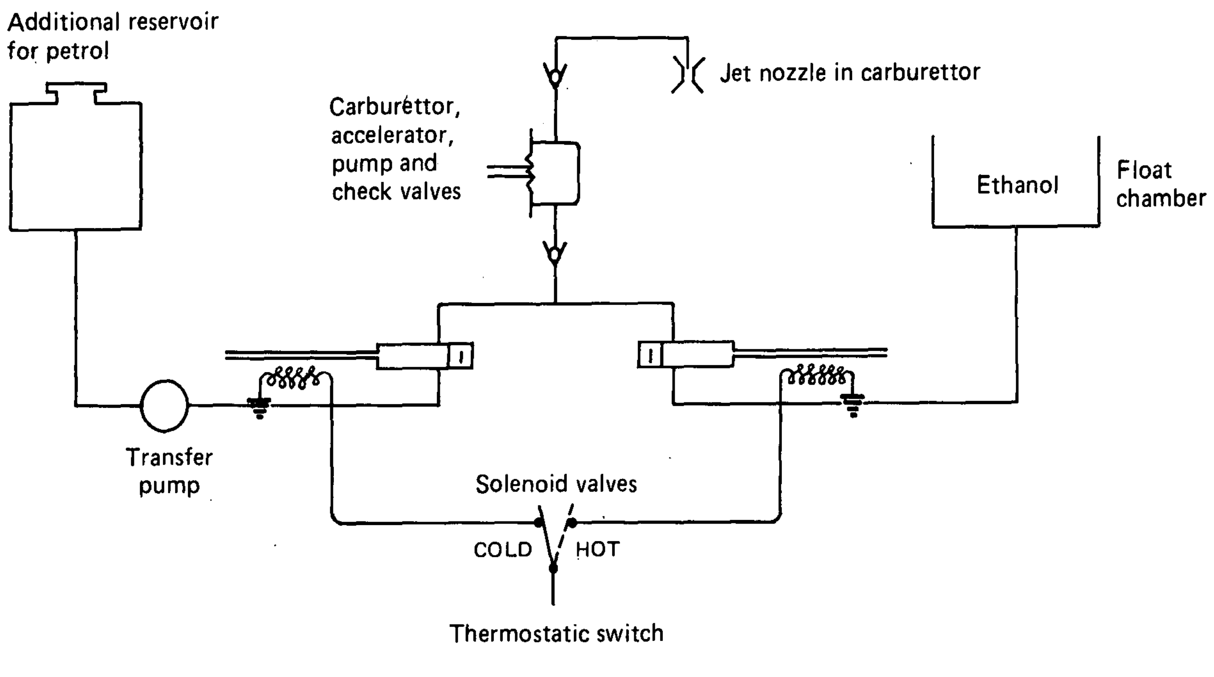

FIGURE 1 Schematic diagram of cold starting mechanism

The carburettor settings were changed because of the differences in heat values and the ratios of air to fuel between petrol and ethanol (Appendix I). Modifications were also carried out on the accelerator pump to discharge 2,56 mℓ $stroke^{-1}$. A conventional twin-choke down-draught carburettor was used.

Ethanol has a higher latent heat of vaporisation than petrol and therefore requires more heat for vaporisation. Fuel should enter the combustion chamber partly in the form of small droplets and partly as a vapour. If the fuel does not enter the cylinder in this form, the engine will not run smoothly. To obtain good vaporisation and an even distribution of the air-fuel mixture to all four cylinders, additional heat must be supplied. A water jacket was built to encase the entire inlet manifold below the carburettor. The engine coolant was thus used as a heat source. The air intake tube situated above the exhaust manifold on this cross-flow engine draws heated air into the carbutettor via the pre-cleaner filter assembly.

The high density foam plastic float and the synthetic rubber float level control valve tip are degraded in ethanol so they were replaced with brass parts. Ethanol is also more prone to pre-ignition than petrol, so spark plugs with a colder heat range were used. Because the terne plating used in fuel tanks would be attacked by ethanol, the fuel filters in the tank and carburettor were removed and were replaced by one large in-line filter in front the fuel pump. Ignition timing was set at 4° BTDC (before top dead centre) at 800 rpm. All other settings and adjustments were the same as those of the standard petrol engine.

During the tests carried out in Cape Town, difficulties were experienced with cold starting because the high latent heat of ethanol prevented the correct amount of vaporised fuel from reaching the cylinder in the spark ignition engine. This was most noticeable when ambient temperatures were below 15°C. This difficulty was overcome by introducing small amounts of petrol into the carburettor during the starting operation. The cold starting system that was devised is shown in Figure 1.

Two solenoid valves, controlled by a thermostatic switch, determine whether petrol or ethanol is discharged by the accelerator pump when the accelerator pedal is depressed. Once the temperature of the engine reaches approximately 55°C this thermostatic switch, sensing the water temperature, will shut off the petrol supply to the accelerator pump and open the ethanol supply. The accelerator pump is, therefore, able to deliver either ethanol or petrol, depending on the temperature of the engine coolant.

To assist cold starting a push-button switch, located on the steering column console, is briefly depressed to operate the transfer pump which forces petrol into the carburettor throat. An electric current flows to the transfer pump and as it is drawn from the starter-motor solenoid the pump can only be operated whilst cranking the engine. With these modifications, the vehicle was easier to start and drive when cold.

Vehicle Performance

Power output

The engine was bench tested and then installed in the vehicle. The carburettor was adjusted and jet sizes were selected to give the leanest part load mixtures to maintain smooth running of the engine. A lean running mixture is necessary for low fuel consumption. The maximum power produced on the bench test was 67 kW which is less than the rated engine output of 72 kW which occurs when operating on petrol. The measured engine power curve is shown in Figure 2.

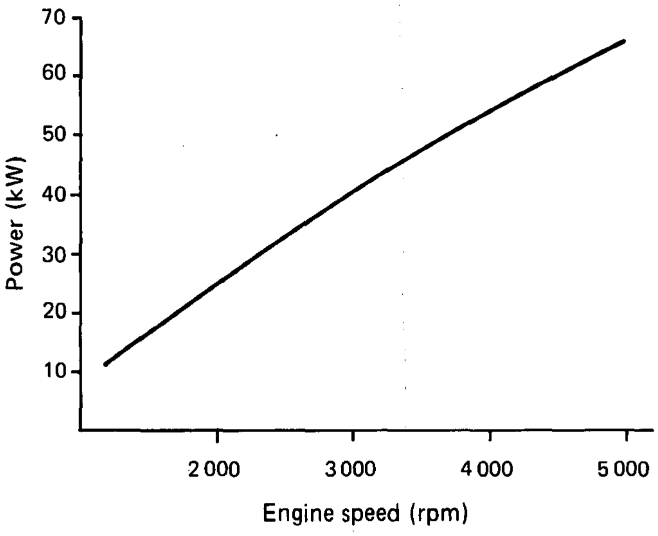

FIGURE 2 Measured engine power curve

Road testing

After a 2 to 3 minute warm-up period no acceleration problems occurred. The petrol starting mechanism was removed as it was not necessary in the climate in which the vehicle was operating. However, it must be emphasised that a starting mechanism would be essential where lower temperatures would be encountered. Starting on pure ethanol presented no problems after the warm-up period and only two to three cranks of the starter were required before the engine fired. A manual choke would be preferable to the automatic choke which was fitted to this vehicle. When the engine was well-tuned, its general performance was similar to the petrol version when pulling away from rest and accelerating when overtaking. The running of the engine was improved if the revolutions were kept slightly higher than those for a conventional petrol-fuelled engine. This meant that changing to a lower gear had to be made sooner than normal. In all other respects the performance of the experimental vehicle, including engine noise and 'ground-feel', was similar to that of the standard vehicle.

Fuel consumption

Because the energy content of a litre of ethanol is about 46% less than that of a litre of petrol, the volumetric fuel consumption is higher. The average monthly fuel consumption ranged from 11 to 20ℓ 100 km^{-1}, depending on the route, the driver, and the tuning of the vehicle. The average fuel consumption for the entire test period was 15,6ℓ 100 km^{-1}.

Fuel consumption tests at constant speeds were conducted and these results were compared with the results obtained by the motor magazine ('Car'[1]) for a similar 2ℓ petrol model. The specific fuel consumption figures shown in Table 2 were obtained after a new cylinder head was fitted and because it had been decided not to skim the new cylinder head to increase the compression ratio, the fuel consumption figures were higher than would otherwise have been expected.

TABLE 2

Specific fuel consumption figures for the ethanol- and petrol-fuelled vehicles

Speed (km h^{-1})	Fuel consumption (ℓ 100 km^{-1})	
	Ethanol vehicle	Petrol* vehicle
60	11,45	6,24
80	11,90	7,26
100	13,50	8,73
120	17,60	–

* 'Car'[1]

These results show when compared with the petrol-fuelled vehicle, the ethanol-fuelled vehicle used 64% more fuel at 80 km h^{-1} and 55% more fuel at 100 km h^{-1}.

A computer was fitted to the dashboard to monitor the distance travelled and fuel consumption. The computer was calibrated and was accurate. However, a drop in voltage during the starting procedure often resulted in the computer losing its memory. This problem was overcome when an auxiliary battery was installed to supply the computer directly. Towards the end of the test programme fuel starvation was considered to be the reason for poor performance. To provide a more direct route for the fuel to the carburettor, the computer was disconnected, thereby reducing the length of plastic and rubber tubing that could be corroded by the fuel.

Maintenance

Severe fuel blockages occurred during the early stages of testing as the in-line fuel filter became blocked. When the tank and blocked fuel filter were examined, dirt was not found in the system, but the paper filter element had become swollen and impervious, probably due to the water in the ethanol. No damage to the fuel tank occurred so this additional filter was considered not to be necessary. Only the filter in the carburettor inlet was replaced.

The carburettor required frequent cleaning of its fuel passages and jets due to the ethanol degrading the aluminium carburettor housing and the rubber and plastic fuel-line system.

The most serious problem was erosion of the standard exhaust valve seats in the engine. This was first noticed when the vehicle had completed 30 000 km, and severe misfiring, poor starting and loss of power occurred. Since there were no lubricating properties in the fuel, the valve seats eroded and the tappets had to be frequently adjusted. When the vehicle had completed 45 000 km, valve clearances could no longer be adjusted and a new cylinder head had to be installed. The new cylinder head was not skimmed to raise the compression ratio because the engine was to be converted to operate on petrol at 50 000 km. After the installation of the new cylinder head the performance of the vehicle was good and fuel consumption did not increase markedly above the average. The first long trip with the new cylinder head gave an average fuel consumption of 13,2ℓ 100 km^{-1}. However, the exhaust valve seats in the new cylinder head eroded so quickly that the tappets had to be reset after only 2 000 km. The poor performance of the vehicle after a further 2 000 km, due to the small valve clearance, led to the decision to terminate the programme.

Examination of the cylinder head revealed black, rubbery deposits in the inlet manifold branches which were assumed to be the remains of eroded fuel lines. The absence of carbon deposits on either the piston crowns or cylinder head confirmed that ethanol is an extremely clean burning fuel.

Spark plugs did not clog but tended to erode when the timing was too far advanced. The mechanical fuel pump was replaced twice.

Normal engine services were carried out and oil changes were made at regular intervals of about 6 000 km. An oil sample was taken at each oil change for chemical analysis and the various metals present in the oil samples at each oil change are shown in Figure 3. The levels of metal concentration indicate average engine wear patterns.

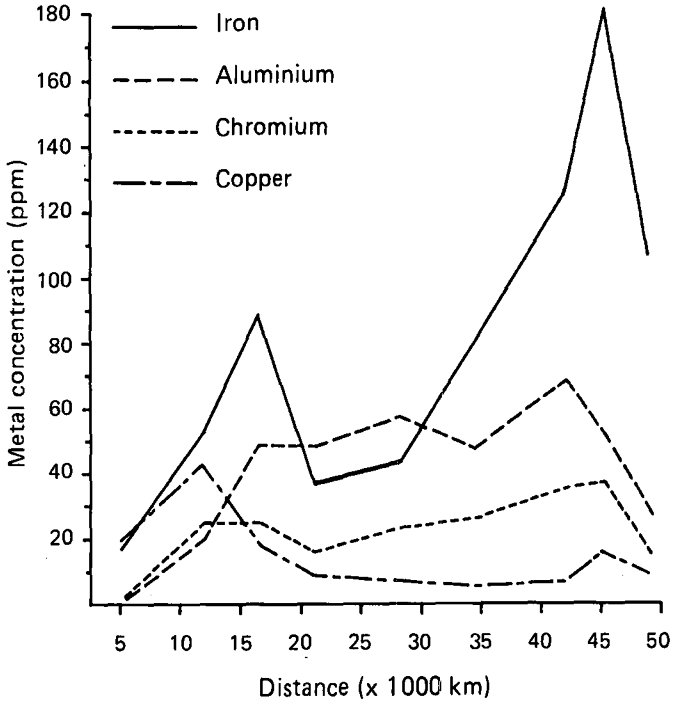

FIGURE 3 Metal concentrations in oil samples

Engine Wear Patterns

The engine of the test vehicle was completely dismantled at 49 000 km, the main components were checked, and the engine wear patterns are listed in Table 3.

TABLE 3

Measured engine wear of test vehicle at 49 000 km

Component	Measured wear
Cylinder liner	0,05 mm and 0,55 mm ovality
Crankshaft:	
main journals	0,01 to 0,02 mm – no ovality
crank journals	No wear
Piston:	
ring groove tolerance	0,10 mm
rings gap	0,90 mm
Cylinder head:	
exhaust valve seats	Severely worn
exhaust valve guides	Slightly worn
cylinder head	Not warped

These results show than engine wear was normal except for the valve seats. The results of the oil analyses correspond with the observed engine wear patterns.

Conclusions

Both experience and valuable information have been gained from this project. It has shown that a conventional petrol-fuelled engine can be converted to operate on hydrous ethanol which will perform satisfactorily under local test conditions.

Adequate fuel consumption figures were obtained when the engine was well-tuned and it was found that the general performance and smooth running of the engine were similar to the petrol counterpart engine. Acceptable engine wear patterns were obtained when pure ethanol was used as the combustible fuel in a modified standard engine designed for petrol fuel, but petrol had to be used in the cold-start warm-up operation particularly at lower ambient temperatures.

Certain changes would be necessary to improve the durability of the engine and the general performance of the test vehicle. These changes are the addition of a lubricating agent such as castor oil to the fuel or the hardening of the exhaust valve seats to increase their durability.

The fuel tank, fuel lines, carburettor, fuel pump and filters should either be manufactured from or treated with alcohol resistant materials as this would eliminate the minor maintenance that was required on the test vehicle.

An electronic ignition system with a higher voltage would simplify maintenance and improve the spark properties, and a manual choke would enable the driver to control this mechanism more effectively and economically.

Acknowledgements

The author wishes to express his appreciation for their research, support and assistance throughout this project to the Energy Research Institute at the University of Cape Town, and particularly to Mr A Yates; BP SA (Pty) Ltd for supplying the lubrication for the project vehicle and the chemical analyses; to Mr K Gorrett, the Workshop Foreman at the South African Sugar Association Experiment Station, for his contribution towards this project; and to the National Chemical Products, who supplied the denatured ethanol used in the test vehicle.

REFERENCE

1. 'Car' (October 1982). Ford Cortina 2000 GL (Series 5) 26(9): 106–109

APPENDIX I

Ignition timing: 4° BTDC at 800 rpm

Spark plugs: Champion F7Y

Carburettor modifications

	Primary	Secondary
Main jets	1,80	1,75
Air correction jet	1,40	1,25
Idling jets	0,70	0,75
Accelerator pump jets	0,90	0,55
Emulsion tube	F 66	F 66
Venturi diameter (mm)	26	27
Needle valve	2,50	
Float height	41	
Power economy jet	2,40	
Full power enrichment jet	1,90	
Accelerator pump delivery	2,56 mℓ stroke^{-1}	