EVALUATION OF TRACTORS THAT HAVE BEEN MODIFIED TO OPERATE ON ETHANOL

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Abstract

The various modifications, differing in cost and complexity, available to adapt diesel engines for operation on hydrous ethanol, are presented. Of these, one option is a complete conversion to spark ignition and another is a modification of the ethanol to allow it to be used in slightly adapted compression ignition engines. The practical implications of the use of both of these modifications were evaluated at the South African Sugar Association Experiment Station by adapting two tractors differently for operation on ethanol. Their performances were then determined and compared with that of a standard diesel tractor of the same make and model. Dynamometer tests, road haulage tests, and general evaluations of the rates of performing field work, were carried out to make these comparisons. It was found that the power and torque outputs, speed, haulage capacity, and rates of performing field operations of the tractors operating on ethanol were similar to those of the diesel tractor, but the fuel consumption of the former was about twice as high.

Introduction

Alcohol and alcohol blends are used as liquid fuel in many countries and considerable progress has been made in developing special engines or modifying standard engines for operation on these fuels. Ethanol has proved to be feasible as a fuel for spark ignition engines in Brazil where 1,8 million cars were operating on alcohol and 8,8 million vehicles were operating on gasohol by the end of 1984. More than 95% of all new cars sold in Brazil (600 000 per year) operate on pure ethanol (van Niekerk[1]).

The current crude oil price (*c* $18 per barrel) is such that there is no economic incentive to substitute alcohol for diesel fuel at present. However, diesel fuel substitution could reduce South Africa's dependence on foreign suppliers. It may also be economical for farmers to produce fuel for their own use on a co-operative basis.

Various modifications are available to adapt diesel engines for operation on alcohol.

Ethanol-diesel blends

Exhaustive tests have been carried out by the Department of Agricultural Engineering at the University of Natal on the use of various ethanol-diesel blends in standard diesel-operated tractor engines. Blends containing up to 15% ethanol have been found to be acceptable for field conditions. The ethanol content can be increased if suitable ignition improvers are used. The use of ethanol-diesel blends would be the first option for reducing diesel demand on a short term, large-scale basis (Vosloo[2]).

Dual fuel systems

Diesel can be used as a pilot fuel with a small amount being injected to initiate combustion, followed by the injection of alcohol to complete the combustion process. Using this system diesel substitution of up to 92% is possible but separate injection and fuel supply systems are required, which are expensive. As an alternative to dual injection, ethanol vapour may be fed into the airstream in combination with diesel injection, resulting in diesel substitution up to 60%

Spark ignition

Diesel engines can be converted to spark ignition with either fuel injection or carburation for operation on 100% ethanol, but considerable engine modification is required. Modifications include a reduction in the compression ratio and a new governor system in addition to the altered fuel supply system.

Additives

Additives have been developed to improve the ignition characteristics of ethanol sufficiently for use in a diesel engine. An additive package would include a rust inhibitor, a lubricant, and a cetane improver. Modifications for a diesel engine to operate on ethanol and additives would be confined to the fuel supply system. Reconversion for operation on diesel fuel could be easily achieved.

Experimental procedure

Staff at the Experiment Station of the South African Sugar Association considered it necessary to evaluate as many of the variations as possible, in an attempt to identify the most practical and economic options available, if ethanol were to become a viable tractor fuel for use in the sugar industry.

Modifications using locally developed components

The feasibility of modifying a standard diesel engine with locally developed or available components was investigated first. The Energy Research Institution at the University of Cape Town was commissioned in 1982 to modify an ADE4.236 engine (subsequently fitted to a Ford 5610 tractor) for operation on ethanol. This entailed reducing the compression ratio, fitting a specially designed inlet-outlet manifold to accommodate a carburretor, replacing the diesel injectors of the cylinder head with spark plugs, and providing a distributor and a governor.

During the test period at the La Mercy farm of the Experiment Station various other changes were made to the engine in an attempt to improve the day-to-day operation of the tractor. The manifolds, carburettor, governor and distributor with timing gears were replaced by more suitable imported units.

The performance of the tractor was extremely erratic. Frequent adjustments were required for it to operate smoothly. While haulage performance measured in tons of cane transported per hour was occasionally better than that recorded from diesel-operated tractors of similar engine capacity, fuel consumption was unacceptable, frequently exceeding 30 $l\ h^{-1}$.

This project was terminated at the end of 1986. At the time it was concluded that locally developed components could not successfully be used to modify standard diesel tractors for practical day-to-day operation on ethanol fuel.

The next phase of the investigation, therefore, entailed the evaluation of imported, tested components.

Modifications using imported components

Three Massey Ferguson 275 haulage tractors of similar specification, fitted with the following variations of the Perkins (ADE) 4.236 engine were evaluated during 1987:

Tractor 1: standard diesel engine

Tractor 2: engine from Brazil modified with carburettor and spark ignition

Tractor 3: standard diesel engine but with special fuel system to allow operation on ethanol with ignition improver.

According to the manufacturer's specifications the standard diesel engine should produce 48 kW pto power at 2 200 engine rpm.

The compression ratio of the Brazilian engine (Tractor 2) is 10 : 1 compared with 16 : 1 for the standard diesel engine. A nickel-plated down-draught carburettor and a transisterised ignition system with centrifugal and vacuum advance were fitted. As an aid to starting in cold weather, petrol can be injected into the airstream at the carburettor intake.

Modifications to the engine of Tractor 3 were confined to the fuel supply system. A special in-line injector pump with matching injectors is used for higher fuel delivery. These special components were obtained by Fedmech from Moteurgaro, a French company. Fedmech also fitted the engines to Tractors 2 and 3 and prepared them for the test.

The fuel used for Tractor 2 was commercial grade hydrated ethanol (94%). For Tractor 3 the ethanol was treated with 'Blendol-MW', a Chemical Resources (Pty) Ltd formulated product. Blendol-MW contains ignition (cetane number) improver, a lubricant, and corrosion inhibitor. Blendol-MW was added to the hydrated ethanol, accounting for 6% of the fuel.

Torque (Nm), power (kW), and specific fuel consumption (SFC) in l/kWh were measured on a M&W P2000 pto dynamometer for each tractor. Engine characteristics could be compared and any deviations in performance from those expected could then be determined.

The dynamometer evaluation was followed by haulage tests conducted on a tar road between the La Mercy farm of the Experiment Station and the Mount Edgecombe sugar mill. The route covers a distance of 9 km with gradients ranging from +6 to −6%. Each tractor completed four trips along this route, pulling trailer loads ranging from 4,2 to 12,8 tons. Loads were checked on the weighbridge at the sugar mill and combinations of bundles of sugarcane and steel blocks were used as ballast.

Fuel consumption was recorded with a Micro Oval II fuel flow meter which operated an electro-mechanical counter. This information was recorded on a tape recorder mounted on the tractor. Speed was determined by measuring the time required to travel set sections of the route. The tractor operator endeavoured to maintain maximum speed at all times.

The road haulage tests were followed by evaluations of Tractors 1 and 2 performing normal field work at La Mercy, while Tractor 3 was included in the tractor haulage fleet at the Sezela estate of CG Smith Sugar Company. For more precise comparisons, Tractors 1 and 2 were timed while carrying out specific tasks on defined areas. During these tests, differences caused by the operators' techniques were eliminated by using the same driver for both tractors. The effects of soil type and soil moisture were reduced as far as possible by performing each operation with both tractors in the same field and on the same day. The tractors used the same implements for similar operations. After the field trials, the tractors were again tested on the dynamometer.

Results and discussion

Dynamometer tests

Initially Tractor 3 only produced 38 kW on the dynamometer. The output of the injector pump was changed and the fuel delivery per stroke was increased. Engine output subsequently increased to 46 kW but specific fuel consumption also increased.

Results of the dynamometer tests are shown in Figures 1 (power), 2 (torque), and 3 (SFC). Maximum power output of the 3 tractors was similar, with differences being mostly due to varitions in the high idle speed settings. The diesel-fuelled tractor's torque was about 6% higher than that of the ethanol-fuelled tractors, indicating that its lugging ability should be better than that of the ethanol-fuelled tractors. This expectation was confirmed during the road tests as the operator noticed that more frequent gear changes were needed for the ethanol-fuelled tractors.

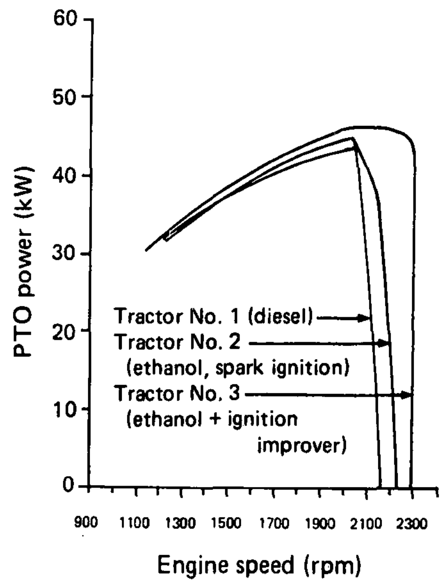

FIGURE 1 Comparison of pto power at start of test.

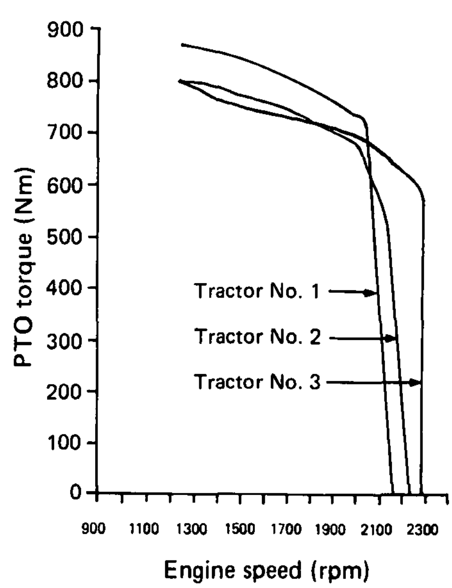

FIGURE 2 Comparison of pto torque at start of test.

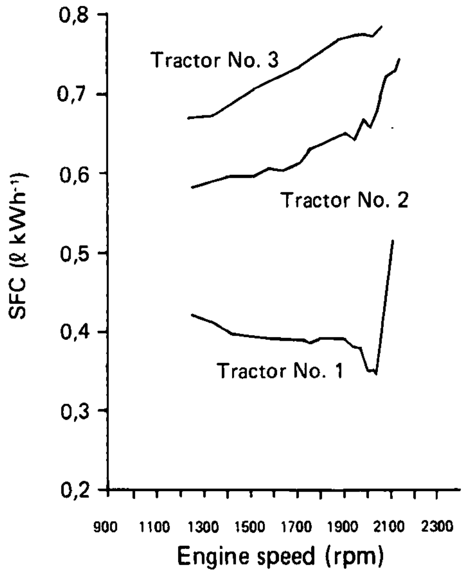

FIGURE 3 Comparison of specific fuel consumption at start of test.

The SFC of the ethanol-fuelled tractors was greater than that of the diesel-fuelled tractor. At the rated speed of the engine of Tractor 1 the SFC of the engines of Tractors 2 and 3 were about 66 and 98% higher respectively than that of the diesel derivative. The relatively poor SFC of the engines adapted for ethanol improved at engine speeds in the over load region and at 1 500 rpm it was 40 and 60% higher than that of the diesel for Tractors 2 and 3 respectively.

Road tests

Speed and haulage capacities recorded during the road tests of the three tractors were very similar. Average speeds (Figure 4) decreased with increased loads; but the haulage capacity, ie the product of speed and load, increased (Figure 5). It is interesting to note that in speed and haulage capacity Tractor 3 outperformed the other two at loads exceeding 5 tons. This was more as a result of the difference in high idle speed setting than engine output. From Figure 5 it appears that higher loads than those used for testing could have resulted in better haulage performances, even though the speeds would have been slower.

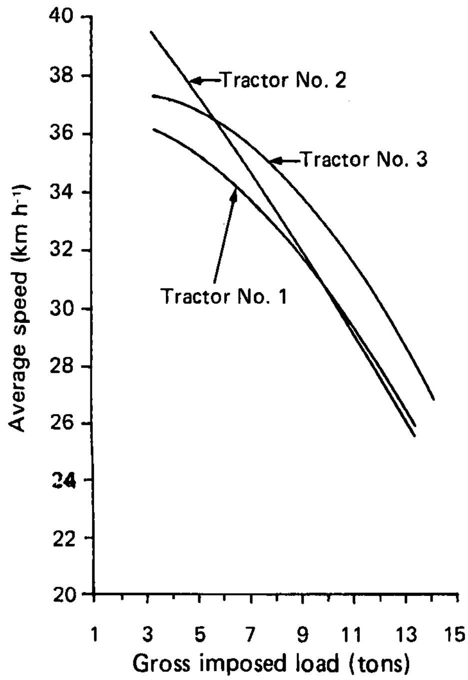

FIGURE 4 Average speed during road tests.

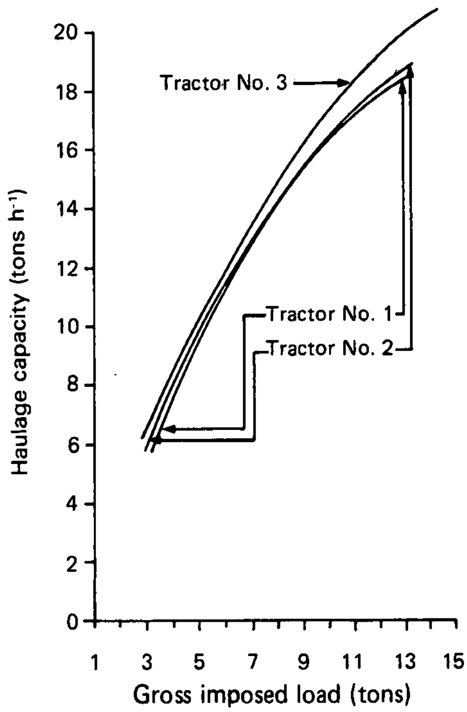

FIGURE 5 Haulage capacity.

For each of the tractors the SFC (measured in l tkm⁻¹ for the road tests) reduced as load increased, initially showing a rapid decline which later evened out (Figure 6). The SFC's of the two ethanol powered tractors were similar but were considerably higher than that of the diesel tractor, varying from 74% more with a 5-ton load to 90% more with a load of 12,5 tons.

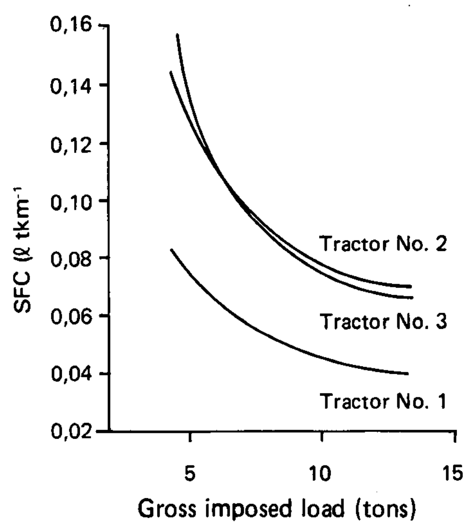

FIGURE 6 Specific fuel consumption during road tests.

Field tests

The results of the evaluation of Tractors 1 and 2 performing general field work are given in Table 1. Measured in l h⁻¹ the fuel consumption of the ethanol-fuelled tractor was 240% of that of the diesel. Results of the more formal tests are given in Table 2. Five different operations were performed under controlled conditions. The fuel consumption of the ethanol-fuelled tractor varied from 196 to 285% of that of the diesel-fuelled tractor with an average increase of 220%. The productivity ratings of the two tractors were very similar, with that of the diesel-fuelled tractor being about 7% higher than that of the ethanol-fuelled tractor for the whole test.

Table 1

Comparison of general tasks performed by Tractors 1 and 2

Operation	Tractor 1 (diesel)			Tractor 2 (ethanol)		
	Hours	Litres	l h⁻¹	Hours	Litres	l h⁻¹
Hauling	39,1	170,0	4,40	65,7	703,9	10,70
Grading	26,0	111,0	4,27	23,0	283,9	12,03
Mowing	95,8	415,0	4,33	285,9	3 249,9	11,37
Ripping	5,2	27,0	5,19	3,6	30,3	8,42
Ploughing	44,3	275,0	6,21	8,6	122,0	14,19
Total	209,4	998,0		386,8	4 390,0	
Average			4,77			11,35

Tractor 3 initially outperformed equivalent diesel haulage tractors (13,51 compared with 10,14 tc h^{-1} delivered; PG Braithwaite, personal communication). The high idle setting of Tractor 3 was then reduced because speeds attained on infield roads were regarded as unsafe. Thereafter the haulage capacity of Tractor 3 was similar to that of the other tractors, but the operators complained that the power output was too low. The fuel consumption of Tractor 3, measured in l h^{-1}, was 140% higher than that of the diesel tractors (PG Braithwaite, personal communication).

After completion of the field trials the tractors were again tested on the dynamometer. By this time Tractor 2 had operated for 775 hours and Tractor 3 for 517 hours.

The torque and power curves of Tractor 1 were essentially the same as at the start of the evaluation period. The torque output of Tractor 2 remained the same but the maximum power measured was about 1 kW lower than at the start of the evaluation (Figure 7). This was probably due to a change in governor response. SFC for Tractors 1 and 2 was similar to that found previously, with the erratic SFC of Tractor 2 (Figure 7) again being ascribed to inconsistent governor response.

Torque and power developed by Tractor 3 were so poor that it was decided to recalibrate the fuel pump and to check the operation of the injectors. The maximum compression in the combustion chambers was found to be as specified.

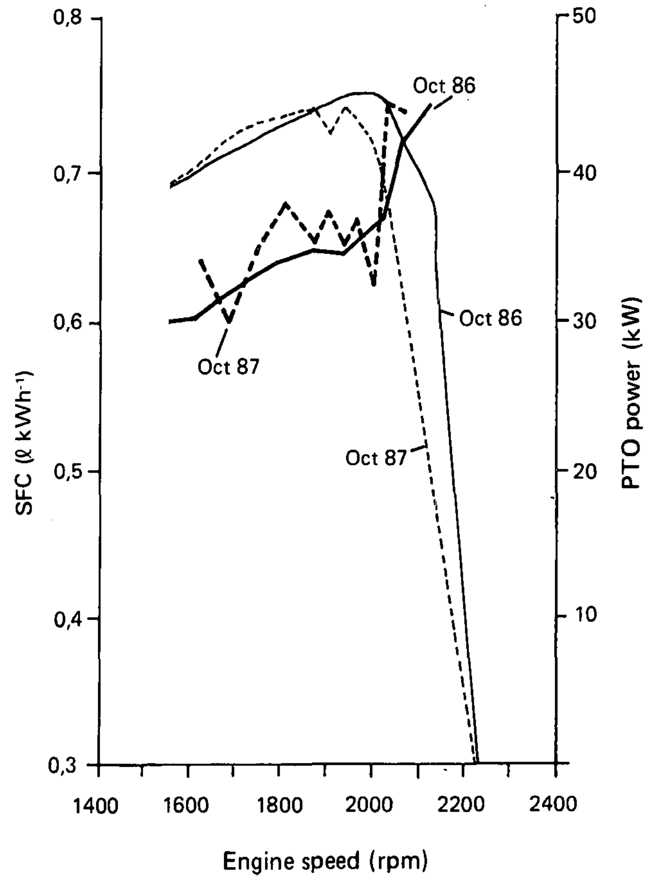

FIGURE 7 Initial and final pto performance of spark ignition ethanol tractor.

The effect on power output and SFC of different fuel deliveries was measured. For this purpose the pump was removed 4 times and calibrated on a test-bench to deliver 11, 14, 15 and 16 cm^3 100^{-1} shots at 750 r min^{-1} on standard test fuel. After each calibration the pump was re-installed on the tractor and the tractor tested on the dynamometer. Results are shown in Figures 8 and 9.

Table 2

Formal field test results

Operation	Soil type or ground-cover	Tractor 1 (diesel) Fuel consumption (l h⁻¹)	Tractor 1 (diesel) Productivity (ha h⁻¹)	Tractor 1 (diesel) Fuel consumption (l ha⁻¹)	Tractor 2 (ethanol) Fuel consumption (l h⁻¹)	Tractor 2 (ethanol) Productivity (ha h⁻¹)	Tractor 2 (ethanol) Fuel consumption (l ha⁻¹)
Ploughing	Middle Ecca	7,78	0,41	19,05	14,04	0,38	37,28
Ploughing	Lower Ecca	8,95	0,46	19,51	21,74	0,39	55,52
Discing	Recent Sands	11,97	1,32	9,04	28,64	1,47	19,48
Discing	Middle Ecca	9,30	1,04	8,92	21,97	1,06	20,78
Discing	Lower Ecca	10,35	1,09	9,48	21,54	1,05	20,44
Discing	Middle/Lower Ecca	9,19	1,06	8,68	21,66	0,98	22,00
Discing	Middle/Lower Ecca				23,42	1,13	20,81
Ripping	Middle/Lower Ecca	9,64	1,03	9,32	21,35	1,15	18,61
Ripping	Middle/Lower Ecca				17,89	1,00	17,89
Mowing	Grass	6,49	1,14	5,71	15,07	1,11	13,56
Fertilizing	Middle Ecca	4,00	3,20	1,25	9,04	2,96	3,05
Average		9,04		8,85	19,88		20,82

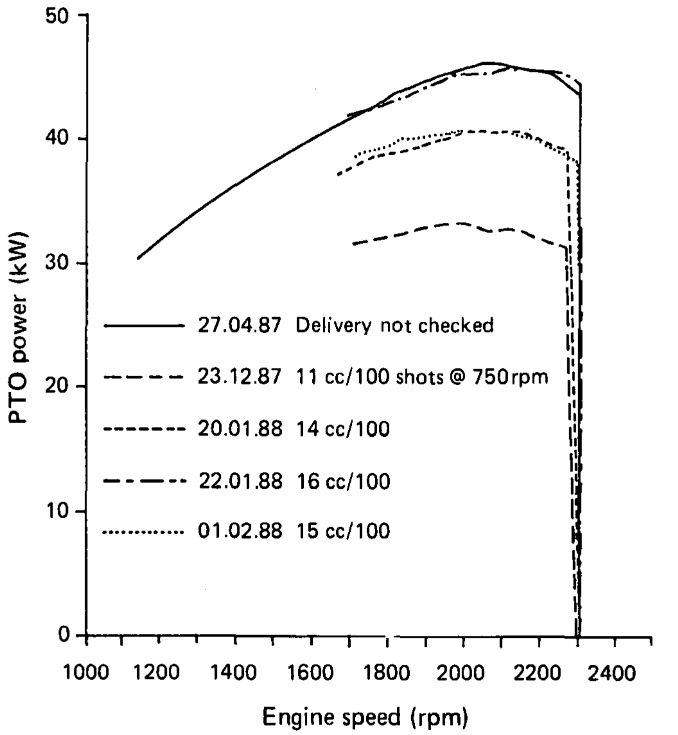

FIGURE 8 Power output of ethanol + blendol tractor for different fuel pump settings.

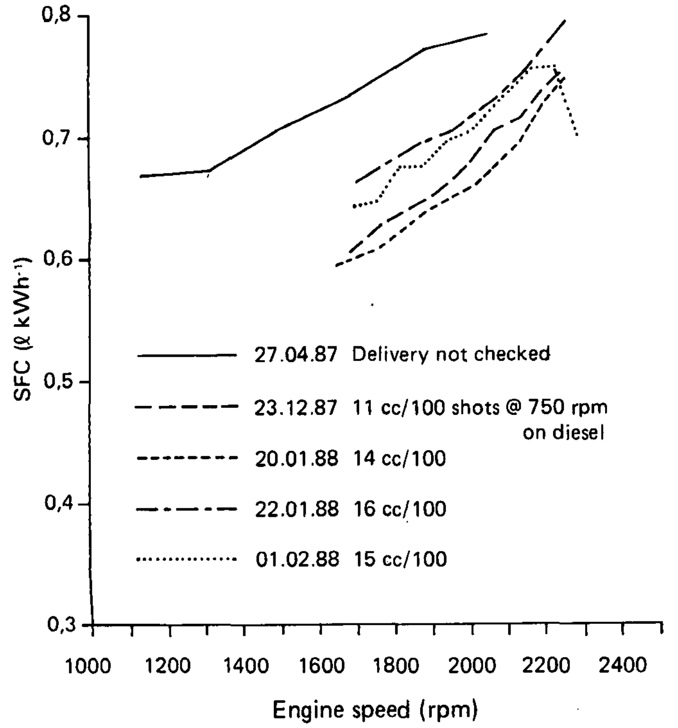

FIGURE 9 Specific fuel consumption of ethanol + blendol tractor for different fuel pump settings.

At a fuel delivery rate of 16 cm^3 100^{-1} shots there was very little response from the governor. It is postulated that when the pump was reset at the start of the test period (27.4.87) to increase maximum output to 46 kW, the pump was set so close to its maximum that the governor could not respond and the tractor was probably operating continuously in the overload range. The tractor was overfuelled, resulting in a higher specific fuel consumption relative to the other ethanol-fuelled tractor (Tractor 2) without a correspondingly higher power output. Figures 8 and 9 show that the best fuel pump setting for Tractor 3 would have been at 14 cm^3 100^{-1} shots to give the most favourable SFC but this would have entailed sacrificing about 3 kW of maximum power.

No major problems were encountered with the tractors. Ingress of water during rain or washing into the electronic ignition control box of Tractor 2 was corrected by sealing the unit with silicone. Tractor 2 always started easily. Although the petrol injection facility was used for ignition early in the morning, the choke was adequate for restarting during the rest of the day. The spark plugs were still in good condition at the end of the project and were not replaced. At the request of the operator a heat shield was attached to deflect exhaust heat. High exhaust temperatures seem to be a characteristic of ethanol-fuelled engines. No problems were experienced in bulk handling or storing of the ethanol in an underground tank.

Conclusions

The performance of the two ethanol-powered tractors evaluated in terms of the engine power and torque output, road speed, and haulage capacity, were similar to that of a standard diesel tractor. The small differences measured could mostly be ascribed to variations in high idle engine speed settings. The performance of the ethanol-fuelled tractor (Tractor 2) during general as well as closely monitored field operations was also very similar to that of the standard diesel tractor.

It can be expected that fuel consumption during road haulage operations will, on average, be about 80% higher for ethanol than for diesel engines. To be economically viable as a tractor fuel for road haulage ethanol should, therefore, be available to the farmer at 56% of the cost of diesel fuel per litre.

For on-farm haulage and field operations, such as ploughing, discing, ripping, mowing, and applying fertilizers, where the engine operates over its entire speed range, fuel consumption of an ethanol-fuelled tractor can be expected to be more than twice as high as that of a diesel-fuelled tractor. To be economical under these circumstances, ethanol would have to be available to the user at 42% of the cost of diesel.

Acknowledgements

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