Eight fuels have been evaluated during this project resulting in the collection of 3,696,000 bytes of information to be digested. It is rather fortunate that a large proportion of this information is not directly required, thus reducing the information to be processsed to a much more manageable 500,000 bytes (approx).

## 5.3 TEST FUELS.

All the emulsions were prepared by Apace Research Ltd. from a common batch of Mobil distillate and C.S.R. Industrial Methylated Spirit.

The ignition improvers used were carefully selected from the literature, previous experience and private communications from other research organisations. Two ignition improvers were chosen for investigation, iso octyl nitrate (ION) for improving the ignition quality of the distillate phase and Triethyleneglycol-dinitrate (TEGDN) for improving the ignition quality of the ethanol phase of the emulsion.

Samples of ION were supplied by The Associated Octel Co. Ltd. (UK). It is also available from other organisations such as Ethyl Corporation who market ION under the trade name DII3. It is available worldwide at competitive prices.

The TEGDN used in the tests was obtained by Perkins Engines Ltd. on behalf of Apace Research Ltd. from Explo-Industrias Quimicas e Explosivos S.A. Brazil. The product containing TEGDN is marketed under the trade name of "Alcoolita". Alcoolita contains 60% ethyl alcohol, 32% TEGDN and the remaining 8% contains dibutylphalate, diphenylamine, castor oil, Maxlube, an anti- corrosive agent and other minor ingredients.

A blend of 13 parts of Alcoolita to 87 parts hydrated (96%) alcohol produces a fuel for use in specially adapted diesel engines. Thus the TEGDN content amounts to 32% of 13% which is equal to 4.16% of the total volume.

It is believed that the present production of TEGDN is in the order of 300 tonnes/month and can be readily expanded.

Initially five emulsions were prepared containing different amounts of ignition improver and their engine performance was compared with that of 100% distillate.
Based on the results obtained another two emulsions were prepared.
Table 9. shows the properties of the various fuels.

Table 9.
Fuel Properties.

| Fuel Id.No | Dist. % | Eth. % | ION % | Density gm/cc | L.C.V. MJ/Kg |
|---|---|---|---|---|---|
| DIST 100 | 100 | | | .849 | 42.75 |
| E20 | 80 | 20 | | .845 | 38.83 |
| E20/.2ION | 79.8 | 20 | .2 | .845 | 38.83 |
| E20/.4ION | 79.6 | 20 | .4 | .845 | 38.83 |
| | | | TEGDN | | |
| E20/2.6TEGDN | 80 | 19.48 | 0.416 | .848 | 38.69 |
| E20/5.2TEGDN | 80 | 18.96 | 0.832 | .850 | 38.55 |
| E20/3.9TEGDN | 80 | 19.22 | 0.624 | .849 | 38.62 |
| E25/3.9TEGDN | 75 | 24.03 | 0.78 | .848 | 37.66 |

NOTES.

1. Distillate was supplied by Mobil
2. "Ethanol" was Industrial Methylated Spirit supplied by CSR Ltd. and contains nominally 5% v/v of water. Its L.C.V. has been taken as 23.96 MJ/Kg.
3. The L.C.V. of TEGDN has been quoted as 13.2 MJ/Kg and the density taken as 1.338 gm/cc.
4. Densities shown in the table are those at 15 deg.C.
5. The surfactant is assumed to be part of the distillate.
6. Fuel identification.
   For emulsions with ION the identification is simply expressed as the alcohol volume and ION volume in the emulsion. Thus E20/.2ION = 20% hydrated ethanol+
   0.2% ION +
   79.8% distillate.(% by volume)
   For emulsions with TEGDN the identification is expressed as non-distillate volume and percentage of non-alcohol constituents of the non-distillate volume. Thus
   E25/3.9TEGDN= 25% non distillate components +
   75% distillate
   where the 25% non distillate component comprises
   21.1% hydrated ethanol +
   3.9% non alcohol components
   and the 3.9% non alcohol components comprise
   3.12% TEGDN +
   0.78% stabilisers, lubricants and anti-corrosive agents.

## 5.4 ENGINE MATRIX TESTS.

A test matrix of 16 load and speed conditions covering the entire engine range was carried out using each emulsion in addition to a distillate datum.

The matrix test conditions were :

3 loads......Full load
2/3 load (nominal)
1/3 load (nominal)

5 speeds.....2000 rpm (nominal)
1700 rpm (nominal)
1400 rpm (nominal)
1100 rpm (nominal)
800 rpm (nominal)

An idle condition at 800rpm and minimum load.

At each matrix condition the following parameters were measured and recorded.

* Engine speed
* Dynamometer load (5 readings)
* Nett fuel consumption (1 reading over 1000 + engine revolutions)
* Air inlet temperature (5readings)
* Air box temperature (5 readings)
* Exhaust temperature (5 readings)
* Engine oil temperature (5 readings)
* Cooling water in temperature (5 readings)
* Cooling water out temperature (5 readings)
* Fuel temperature at fuel pump inlet (5 readings)
* Cooling tower water in temperature (5 readings)
* Cooling tower water out temperature (5 readings)
* Ambient/cold junction temperature (5 readings)
* Needle lift and cylinder pressure readings at one grad intervals commencing at 190 grads BTDC on compression stroke and continuing for 780 grads.Five of the above cycles were repeated at intervals of 180 complete engine revolutions.

The method adopted for the aquisition of of all data for the various test fuels was as follows:

The engine was run at 1700 rpm and approximately 75% load until engine cooling water temperature was stabilised at about 80 deg C. outlet, 50 deg C inlet, sump oil temperature in excess of 80 deg C. and air inlet temperature of 30 deg C. When these parameters were reached a check of the dynamic performance was made by invoking the timing/delay measurement mode. If this was considered satisfactory then the full test matrix was carried out in the following order:

1. Full load -2000 rpm
   -1700 rpm
   -1400 rpm
   -1100 rpm
   - 800 rpm
2. 2/3 load -2000 rpm
   -1700 rpm
   -1400 rpm
   -1100 rpm
   - 800 rpm
3. 1/3 load -2000 rpm
   -1700 rpm
   -1400 rpm
   -1100 rpm
   - 800 rpm
4. Idle - 800 rpm

A check of all major parameters was made prior to executing full run mode at any matrix condition.

The engine remained unaltered for all tests with the exception of timing changes.

The methodology adopted was to compare 20% ethanol emulsion containing first guess quantities of ignition improvers to a 20% emulsion with no ignition improver, and 100% distillate. First guess quantities were 0.2% and 0.4% ION in the emulsion then 2.1% and 4.2% TEGDN in the alcohol phase of the emulsion. All of these fuels were tested at the static timing of 20 deg BTDC to establish the effect of the ignition improvers. From the results obtained the preferred ignition improver was selected together with its optimum required quantity for best thermodynamic engine performance.
The emulsion containing the required quantity of the preferred ignition improver was then compared to 100% distillate at various injection timing swings ranging from 6 deg (engine) retarded to 6 deg (engine) advanced in order to establish the optimum timing. Once the ignition improver, its quantity and the optimum timing were thus established an emulsion containing 25% ethanol plus ignition improver was prepared and compared to 100% distillate.

## 5.5 ENGINE MATRIX TEST RESULTS.

All engine test results are presented separately in:
Appendix 1.,"Engine Results Curves", FIG AP1 to AP125
Appendix 2.,"Engine Results Tables", Page 1 to 56

The results for torque, and its derivatives, shown in Appendix 1., have been corrected for atmospheric pressure only since the air inlet temperature was maintained relatively constant.

The engine results for torque (and power) shown in Appendix 2.have been corrected to standard conditions for atmospheric pressure and temperature as per Australian Standard "Method for Rating and Testing Internal Combustion Engines" AS 1501-1976 (100 kPa and 27 deg.C ).

The most important criteria when assessing alternative fuels for diesel engines, especially fuels containing large percentages of single boiling point, high latent heat of vapourization, self ignition temperature liquids are ignition delay and rate of pressure rise.

The emphasis in this report ( and indeed of the specialised instrumentation ) is therefore directed to these aspects rather than the more conventional ones of torque, power, specific fuel consumption and thermal efficiency. These have not been ignored in the analysis, but the weighting given to them is less than would normally be the case.

Definitions of some of the terms used :

Three different loads have been used in the engine performance and these have been arbitrarily called Full load, 2/3 load and 1/3 load. The actual loads used are:

Full load- The maximum load that can be applied to the engine at any particular engine speed. This is dictated by the fuel delivery, fuel calorific value and thermal efficiency.

2/3 load-This is a load of 11.22 N (2.5 lbf) or torque of 89 NM. applied at any speed.

1/3 load-This is a load of 4.49 N (1.0 lbf) or torque of 35.6 NM applied at any speed.

Engine speeds quoted for comparison purposes are nominal engine speeds. There can be a variation of upto 50 rpm between the nominal and actual speeds. Actual speeds are used in all calculations and graphs.

(a) Commencement of Injection and Combustion, Max. Cylinder Pressure and Max. Rate of Pressure.

FIG AP1 to AP24 show the needle lift and cylinder pressure diagrams obtained on the initial fuels tested. These were:

| | | |
|---|---|---|
| * Distillate | FIG AP1 | -AP4 |
| * E20 | FIG AP5 | -AP8 |
| * E20/2.6TEGDN | FIG AP9 | -AP12 |
| * E20/5.2TEGDN | FIG AP13 | -AP16 |
| * E20/.2ION | FIG AP17 | -AP20 |
| * E20/.4ION | FIG AP21 | -AP24 |

These diagrams show the repeatability of the needle lift and cylinder pressure taken every 360 engine revolutions (Note that while five actual readings were taken every 180 engine revolutions, only the first, third and fifth readings are plotted). The table of results at the right hand side of each of the diagrams gives the average of the FIVE readings.
Typically the needle lift is repeatable at higher speeds and variable at the low speed, low delivery (i.e. idle) conditions. Please note that only the commencement of needle lift is taken into consideration and not vertical separation (which is to some extent influenced by the self tuning characteristics of the transducer system used ). Considerable changes in needle lift, for example FIG AP8, indicate fuel delivery variations resulting in significant changes in combustion characteristics. This would be expected for the CAV DPA pump which exhibits a variable commencement of injection with load. This coupled with metering being accomplished by throttling leads to substantial changes in the amount of fuel injected and dynamic timing. The effect is particularly evident on three cylinder engines.

TEGDN emulsion fuels.
FIG AP25 -AP27 compare max. cylinder pressure, max. rate of cylinder pressure, start of injection and start of combustion of emulsions containing TEGDN with 100% distillate and E20 at different speeds and loads.
At full load there is virtually no difference in max. pressure with any of the fuels. At part loads the percentage difference is greater but the actual pressures are reasonably close between the fuels.
The start of injection at full and 2/3 loads within the 800 to 2000 rpm speed range is almost completely independent of the emulsion used. 100% distillate shows a departure from the other fuels only at 800 rpm exhibiting 2 deg of retard.

At 1/3 load there is a considerable change in the dynamic timing at 1400 rpm for the two fuels containing TEGDN ignition improver. Apart from this point the behaviour of 100% distillate and the emulsions follow the same pattern as at full and 2/3 load conditions.
At this stage there is no reasonable explanation for this phenomena. It certainly is not due to incorrect data aquisition as the max. pressure and max. pressure rate follow suit.
The change in the start of injection at 800 rpm can most probably be attributed to the advance device fitted to this pump which is load, viscosity and fuel bulk modulus sensitive. Its highest sensitivity would lie at the lower speeds where the transfer pressure is also most fuel viscosity sensitive.

The start of combustion at full and 2/3 load,again within the 1100 to 2000 rpm range, is fairly consistent with the 100% distillate and the two emulsions containing TEGDN. The E20 emulsion shows a considerable change in the start of combustion being much later than the other three fuels. Although the 1/3 load appears to be somewhat haphazard, careful study shows that similar conclusions can be drawn, although they are not as obvious when compared to the other conditions.

The max. rate of pressure is most certainly affected by fuel type. The worst (i.e. one exhibiting the highest rate) being the E20 emulsion and the best being the E20/5.2 TEGDN emulsion. The difference is most obvious under full load conditions at the higher speeds. At 2/3 and 1/3 load the difference between 100% distillate and the two emulsions containing TEGDN is much reduced.

FIG AP31 to AP33 show the effect of load at various speeds when using emulsions containing TEGDN compared with E20 emulsion and 100% distillate.

FIG AP37 to AP39 show how the max. pressure, max. rate of pressure, start of injection and combustion vary with emulsions containing TEGDN compared with E20 emulsion and 100% distillate at various speeds and loads.

ION emulsion fuels.
The max. cylinder pressure, max. rate of pressure, start of injection and combustion for the emulsions containing ION are compared to E20 emulsion and 100% distillate in FIG AP28 to AP30, AP34 to AP36 and AP40 to AP42.

The results show a trend similar to that obtained with the emulsions containing TEGDN but not to the same extent.
Thus max. cylinder pressures are almost identical at the full load conditions at all speeds for all four fuels with some divergence at the 2/3 and 1/3 loads.
Max. rate of pressure does decrease with the inclusion of ION to a small but significant degree. Again the main effect is seen at the higher speeds under full load conditions. Start of injection for the full and 2/3 loads is almost identical throughout the speed range for all the emulsions, some deviation occuring when using 100% distillate at 800 rpm. A similar phenomenom takes place at the 1400 rpm, 1/3 load condition to that obtained with the emulsions containing TEGON i.e the start of injection is similar for the 100% distillate and E20 emulsion while the ignition improved emulsions are similar to each other but are somewhat retarded with respect to the 100% distillate and E20.

(b) Fuel delivery, Torque and Specific fuel consumption (S.F.C.)

FIG AP43 and AP44 show the effect of the six initial fuels on the maximum fuel injection pump delivery and maximum torque. The deliveries are very similar for all the fuels tested and thus it can be stated that the fuel pump delivery is relatively insensitive to these particular fuels. It should be noted that the method of obtaining the fuel delivery is indirect. The actual fuel used is measured gravimetrically, then its volume is calculated from its known density at 15 deg C and the fuel pump inlet temperature. The volume so calculated is then divided by the number of injection strokes during the measuring period.
The maximum torque is again very similar for each of the fuels the maximum difference occurs at 2000 rpm amounting to 5%, while the difference for the rest of the speed range is reduced to 2.5%. The S.F.C. for the emulsions containing TEGDN (FIG AP43) shows an apparent high variation, however the effect of the figure scaling must be noted and in fact, the greatest difference shown between the E20 emulsion and the E20/5.2 TEGDN emulsion at

1400 rpm amounts to only 2.5%. The emulsions containing ION (FIG AP 44) show even lower divergence in S.F.C. between the various fuels.

(c) Fuel delivery, Efficiency and Specific fuel consumption. (S.F.C)

TEGDN emulsion fuels.
FIG AP45 to AP48 show the effect of applied load (torque) on the above three parameters at three different speeds with the emulsion containing TEGDN.

Typically it can be deduced that 100% distillate is required in the least amount by comparison to all the emulsions to attain any given torque under the majority of conditions. The worst fuel in this respect is the E20/2.6 TEGDN emulsion. Efficiency varies with the torque and the fuel used e.g. at full and 2/3 loads, (all speeds), maximum efficiency is attained with the E20 emulsion while the 100% distillate shows minimum efficiency at full loads only.
Specific fuel consumption is dependant on the efficiency and fuel calorific value and therefore 100% distillate appears to be superior to the other fuels throughout the load and speed range. The two emulsions containing TEGDN give higher specific fuel consumptions, with the E20 emulsions showing a slight improvement over them.
The disparity in the fuel consumptions is more evident at part loads than at full load.
FIG AP51 compares the fuel delivery, efficiency and S.F.C. under full load conditions directly for the four fuels, 100% distillate, E20, E20/2.6 TEGDN and E20/5.2 TEGDN, and the three speeds.

ION emulsion fuels.
FIG AP48 to AP50 depict the variations in fuel delivery, efficiency and S.F.C. against applied load (torque) at various speeds with the emulsions containing ION.
Once again 100% distillate is required in the least amount compared to all the emulsions to attain any given load although under full load conditions the difference between any of the fuels is negligible. The three emulsions E20, E20/.2ION and E20/.4ION have almost identical performance throughout the load range at the three speeds selected, the exception being 2/3 load at 800 rpm. where greater delivery of E20/.4ION is required to attain the desired load.

The three emulsions (E20, E20/.2ION and E20/.4ION) exhibit higher efficiency under most loads and speeds, the only exception being the 2/3 load, 800 rpm condition using E20/.4ION.
Again the specific fuel consumption of all the emulsions is higher than that of 100% distillate at all loads other than full load. At the full load condition all the fuels give extremely close results.
FIG AP52 compares the fuel delivery,efficiency and S.F.C. under full load conditions directly for the four fuels, 100% distillate, E20, E20/.2ION, and E20/.4ION, and the three speeds.

Based on the results obtained it was projected that the optimum ignition improver would be TEGDN in the ratio of 3.12% TEGDN in the hydrated ethanol. This conclusion was drawn based mainly on matching the ignition delay and the rate of change of cylinder pressure to that of 100% distillate. Although it appeared that ION could be made to match at full load there was some doubt as to whether part load conditions could be matched as well. The amount that would be required was estimated at 0.8 to 1.0% of the total emulsion. Note that these amounts would be greater than those required for emulsions containing TEGDN.

The next stage of evaluation was to establish the effect of changes to static injection timing when using the "optimised E20/3.9TEGDN" emulsion. The E20/3.9TEGDN emulsion was compared to a 100% distillate datum and a full performance matrix test was carried out at 14 deg, 20 deg and 26 deg BTDC static injection timings for both fuels.
Opportunity was taken to evaluate the repeatability of results over long term for the 100% distillate used as reference.

The results for this series of tests were as follows:

(a) Commencement of Injection and Combustion, Max. Cylinder Pressure and Max. Rate of Pressure.

FIG AP53 to AP76 show the needle lift and cylinder pressure diagrams for the two fuels and the various static timings.

| | | | |
|---|---|---|---|
| * | 100% Distillate | 20 deg BTDC | FIG AP53 - AP56 |
| * | " | 14 deg BTDC | FIG AP57 - AP60 |
| * | " | 26 deg BTDC | FIG AP61 - AP64 |
| * | E20/3.9TEGDN | 20 deg BTDC | FIG AP65 - AP68 |
| * | " | 14 deg BTDC | FIG AP69 - AP72 |
| * | " | 26 deg BTDC | FIG AP73 - AP76 |

Again both the needle lift and cylinder pressure show good repeatability at the higher speeds and loads and poor repeatability at the low load, low speed or idle condition.

100% Distillate fuel.
FIG AP77 to AP79 are included to observe the repeatability with time using 100% distillate on these parameters. Some difference is observed in the max. pressure at full load this amounting to 5.5% at 2000 rpm where minor timing change occurred and 8% where considerable retardation (3.7 deg.) of commencement of injection occurred. The repeatability (especially at part loads) is considered very good and if timing would have been re-adjusted for each condition to ensure constant dynamic timing then excellent repeatability would have been attained.

FIG AP80-AP82 show the effect of static timing on the max. pressure, max rate of pressure and the ignition delay. As can be seen the max. pressure at full load increases considerably for a timing change from 14 deg to 20 deg BTDC but the increase in this pressure for the timing change from 20 deg to 26 deg BTDC is small. At part loads the max. pressure tends to be more proportional to the static timing at the higher speeds but follows the characteristics of the full load condition at the lower speeds.
Apart from the 800 rpm condition both the max. rate of pressure and ignition delay tend to be proportional to the static timing and they increase as the timing is advanced.
FIG AP86-AP88 are presented to show the variation in max. pressure, max. rate of pressure and ignition delay with load at the three different timings and three different speeds. It can be seen that both the max. pressure and max. rate of pressure are significantly load sensitive.
The ignition delay shows very little sensitivity to load (in fact it is marginally extended at the lower loads as would be expected from a cooler combustion chamber), it is however affected by the timing.
FIG AP92-AP94 show directly the effect of timing on the four parameters ,Max.Pressure, Max. Rate of Pressure , Commencement of Injection and Commencement of Combustion.

E20/3.9 TEGDN emulsion fuel.
Results for the E20/3.9 TEGDN emulsion (FIG AP83 -AP85, AP89-AP91, AP96-AP98) are virtually identical for those obtained on 100% distillate with the exception that the timing change from 26 deg to 20 deg has a greater effect on max. cylinder pressure under full load conditions.

(b) Fuel Delivery, Torque and Specific Fuel Consumption.(S.F.C.)

100% Distillate.

The delivery at 2000 rpm varies by a max of 4% between that at the 20 deg timing compared to the other two. This could be due to slight governor interference however the magnitude need not be considered of great importance.
Torque increases considerably as the timing is retarded and from the results obtained it could be deduced that further retard could be possible. This does not however take into account that smoke is the limiting factor at approx. 18 deg BTDC.
The specific fuel consumption also decreases with retarding the timing as would be expected from the increased torque without a corresponding increase in delivery. See FIG AP98.
FIG AP100-AP102 show the delivery required to attain a given part load condition at different engine speeds. It can be noted that the major effect of timing on all the parameters (delivery, efficiency, specific fuel consumption) occurs at full load conditions. This is shown more clearly in FIG AP106 where the delivery, efficiency and S.F.C. are plotted directly against the static timing for the various speeds.

E20/3.9 TEGDN emulsion.
(FIG AP100) Delivery is practically identical to that obtained on 100% distillate however the torque does not increase at the same rate with change in the timing. At 26 deg BTDC the torque for both the 100% distillate and E20/3.9 TEGDN emulsion are very similar but at 14 deg BTDC the torque at 1100 rpm is 5.7% lower on the emulsion than on the distillate. Specific fuel consumption follows suit being 5.7% higher on the emulsion at 1100 rpm at the retarded timing.
FIG AP103-105. Typically the thermal efficiency of the E20/3.9 TEGDN emulsion is higher than that for 100% distillate at all speeds and loads in excess of approx. 50%, at comparable timing settings. Below the 50% load the thermal efficiencies for both the distillate and emulsion are identical. Although the thermal efficiency using the emulsion

is at no time lower than that for distillate under identical conditions, the emulsion specific fuel consumption is higher than that for distillate under almost all conditions with the exception of full load at 2000 rpm and 26 deg BTDC timing (FIG AP107).

The results obtained from this test matrix indicate that a retarded timing for both the 100% distillate and E20/3.9TEGDN emulsion is highly desirable to obtain best torque, efficiency and S.F.C. Excessive smoke limits the static timing to 18 deg BTDC when using 100% distillate.

After carefully assessing all the results obtained to this point, it was considered appropriate to prepare an E25/3.9 TEGDN emulsion and set the static timing to 18 deg BTDC. Results obtained were as follows:

(a) Commencement of Injection and Combustion, Max. Cylinder Pressure and Max. Rate of Pressure.

The needle lift and cylinder pressure diagrams are shown in FIG AP108-AP111 for 100% distillate and FIG AP112-AP115 for the E25/3.9TEGDN emulsion. Once again good repeatability is obtained at the higher speeds and loads. The low idle condition, no load and 800 rpm, is worst for repeatability both in terms of timing and start of combustion.

The commencement of injection and combustion for both 100% distillate and emulsion throughout the the speed and load range are virtually identical. The only exceptions to this statement occur at the 800 rpm speed where the emulsion dynamic timing tends to be approximately 1 deg advanced and at 1400 rpm, 1/3 load where this increases to almost 2 deg.

Max. pressures for the two fuels are again almost identical throughout the speed and load range.

Maximum rate of pressure is generally higher for E25/3.9 TEGDN emulsion than for 100% distillate under full load conditions at 18 deg BTDC static timing. Typically the rate increase is approx. 2 bar/ deg which is equivalent to 14% (FIG AP116-AP118).

FIG AP119-AP121 show the variation in ignition delay, max. rate of pressure and max. pressure with torque at different speeds. The ignition delay is identical for 100% distillate and E25/3.9 TEGDN emulsion and the max. cylinder pressures are very similar. The maximum difference between the two fuels occurs in the max. rate of pressure, however, as already pointed out in the previous paragraph this increase with the emulsion amounts to a maximum of only 14%.

(b) Fuel delivery, Torque and Specific Fuel Consumption (S.F.C.). FIG AP122

The fuel delivery using E25/3.9 TEGDN emulsion is marginally higher than with 100% distillate throughout the speed range under full load conditions with the exception of 1700 rpm where it is marginally lower. It could however be considered that the fuel delivery is insensitive to the type of fuel being used.
The maximum reduction in torque occurs at 1700 rpm using the E25/3.9 TEGDN emulsion and amounts to 6.9%. From consideration of calorific value and actual fuel deliveries, the reduction in torque should have been in the order of 13.75%.
S.F.C. does increase with the emulsion, typical increase being in the order of 5.4%.

FIG AP123-AP125 show the effect of torque on the fuel delivery, efficiency and S.F.C. It can be seen quite clearly that increased fuel delivery of the E25/3.9TEGDN emulsion is required to attain the same torque as that obtained with 100% distillate.
The efficiency at loads exceeding 50% is almost always higher with the emulsion the only exception being the 2/3 load condition at 800 rpm. Below the 50% load the efficiencies of the two fuels are very similar.

## 5.6 DISCUSSION OF ENGINE TEST RESULTS.

From the results obtained it can be readily deduced that a stable emulsion containing distillate, hydrated ethanol and ignition improver can be readily prepared using the Apace Research Ltd. emulsifier. It is also apparent that this emulsion can be formulated to obtain the ignition characteristics of a high quality automotive distillate and that the alcohol content is not limited by thermodynamic considerations. The fact that TEGDN is used as an ignition improver for 100% hydrated ethanol engines should make this obvious.
The maximum amount of ethanol substitution will therefore be governed by other factors, either physical or economic.

The FORD 3000 engine used in these tests exhibited, on 100% distillate, a rather poor thermal efficiency with correspondingly low torque and high specific fuel consumption. The improvement in performance on emulsion was relatively high, in fact much higher than could be reasonably expected. It is suspected that with more developed engines, the extent of performance improvement will be reduced over that obtained with the FORD 3000 engine.

It is to be expected that performance in terms of torque (power) will be reduced in some proportion to the calorific value of the fuel and hence, in the case of emulsions, to the amount of alcohol present. In the majority of cases the power drop will not be directly proportional to the calorific value of the fuel, the increased thermal efficiency and re-adjustment of the injection timing offsetting some of the calculated theoretical change. For example the calculated power drop for an E25/3.9 TEGDN emulsion compared to distillate on calorific value only should be 11.9%. The actual power drop obtained on the FORD 3000 engine amounted to an average of 2.2% when comparing the distillate results at 20 deg BTDC and E25/3.9 TEGDN emulsion at 18 deg BTDC static timing.
It would be unwise to predict this sort of performance for other engines and a more realistic figure would be in the order of 7% power drop when changing from 100% distillate to the E25/3.9 TEGDN emulsion with the static timing optimised.
Should the application demand that full power be restored then the fuel delivery would have to be increased by a corresponding amount.
Generally there are two ways to increase the fuel delivery from a fuel injection pump. One way is to lengthen the injection period while the other is to increase the injection rate.
It would seem that increasing the injection period is the simplest way of increasing the fuel delivery and in the vast majority of instances this will be the case. It must however be borne in mind that a combination of retarded timing and extended injection period could cause late cycle burn to occur in some engines. This would result in loss of thermal efficiency and high exhaust gas temperatures.
Engines fitted with in-line fuel injection pumps having constant beginning of injection control helix would simply require maximum fuel and injection timing re-setting which is a simple operation. Generally an in-line pump has excess fuel capacity of at least 40%. There may however be rare applications where the additional fuel is injected over a sensitive cam radius with resultant high cam stresses.
Increasing the injection period on a DPA distributor type pump results in a change of injection timing and

this timing change would have to be taken into account in addition to any other timing change required. This pump does not possess excess fuel capability and in some instances may already be operated close to its maximum rated fuel delivery. Additionally in some applications the roller- camring contact occurs coincidentally with ( or it may even precede) the delivery port opening. Increasing the delivery period under these circumstances would lead to high cam stresses and cam failure. A change of cam to delivery port phasing can be achieved by a change of either the camring or advance piston but this would affect the torque curve shape of the engine.
Increasing the fuel pump delivery by increasing the fuel injection rate would necessitate larger diameter pumping elements (irrespective of the type of pump). New injector nozzles, hopefully only having larger diameter spray holes, would also have to be fitted. Again there will be instances where a pump is already close to its design limit and a completely new pump would be required. This method, even in its simplest implementation could be considered as economically unsuitable.

## 5.7 CONCLUSIONS ON ENGINE PERFORMANCE.

* The performance of the engine was considerd excellent when operating on ethanol emulsions containing TEGDN ignition improver.
* The amount of TEGDN required is determined by the ethanol content of the emulsion. The optimum amount of TEGDN is considered to be 3.12% of the hydrated (95% v/v) ethanol. Please note that for a 15% ethanol emulsion there is no requirement for an ignition improver.
* The maximum ethanol substitution should be considered as 25% of the emulsion resulting in changes limited to minor adjustments only.
* Although not commented upon elsewhere, noise levels using the emulsion containing TEGDN were comparable to those using 100% distillate.

# 6. TOYOTA LANDCRUISER.

A Toyota Landcruiser Model HJ 45RV-KCQ fitted with an H series engine (indirect injection) has been used by Apace Research Ltd. for the evaluation of a number of emulsions over a period of years. Most of the evaluation period ( 3 years and 50000kms) was spent operating on 15% ethanol emulsion containing no ignition improvers. No problems have been experienced during this period and average road operating fuel consumption was virtually identical for both 100% distillate and 15% ethanol emulsion (12.5 km/litre). Cold starting, although always satisfactory when used with glow plugs, resulted in a period of knock during the engine warm-up period with both the 100% distillate and 15% ethanol emulsion. The warm up period tended to be longer ( 20 seconds instead of 10 seconds) with the emulsion.

Once the optimum ignition improver had been established on the engine test bed, a road performance test was carried out.

The fuel selected for this test was E20/3.9 TEGDN where the 20% ethanol content of the emulsion contained 3.12% TEGDN. It was considered that this would probably be the most widely used fuel where little or no engine/ fuel injection equipment changes would be required and yet have similar thermodynamic properties to that of distillate.

A long, straight and level stretch of road was selected for the vehicle road testing. A number of full acceleration tests were carried out at 30 to 60 km/hr in third gear , 60 to 80 and 60 to 90 km/hr in top (fourth) gear. The times obtained during these acceleration tests were averaged and are shown in Table 10. It should be noted that run to run variations in the measured times exceeded the average difference between the fuels. For example the time for the 60 to 80 km/hr test using distillate varies from 10.96 to 12.26 seconds giving an average of 11.65 seconds while for the E20/3.9TEGDN emulsion the time varies from 11.59 to 13.02 seconds with an average of 12.175 seconds.

The reduction in power when using the E20/3.9 TEGDN emulsion (although it appears to be considerable when times are taken into account) is not reflected in the driveability of the vehicle. The fuel pump delivery was temporarily reset, by allowing an extra 0.25 mm control rack travel, and it can be seen that power could be quite easily regained if absolutely essential.

TABLE 10. Acceleration Times for Toyota Landcruiser.

| Speed Range km/hr | 30-60 | 60-80 | 80-90 | 60-90 |
|---|---|---|---|---|
| DIST 100 | 8.22 | 11.65 | 6.39 | 18.04 |
| E20/3.9TEGDN | 8.56 | 12.175 | 7.445 | 19.62 |
| E20/3.9TEGDN (0.25 mm rack adjustment) | 8.23 | 11.4 | 6.9 | 18.3 |

The engine performed smoothly on the E20/3.9TEGDN emulsion and virtually no smoke was emitted even when operating on excess fuel on start up. Cold starting was found to be superior to that on 100% distillate in as much that glow plugs needed to be used for shorter periods (approx 50%) at any given ambient temperature and there was an almost total absence of the cold start knock.

## 7. RECOMMENDATIONS.

* From the results obtained from these tests there would appear to be no thermodynamic barriers to prevent the introduction of ethanol emulsions containing ignition improvers into existing diesel engined equipment. As has been shown, the emulsions can be tailored to give a performance equal to that of distillate without the need for any engine changes, with the exception of possible minor adjustments to fuel injection equipment.
Consequently engine manufacturers and fuel injection equipment manufacturers should be approached and test programmes established in conjunction with the traditional fuel distributors and potential fuel (alcohol) producers/ suppliers within developing countries.

* Large scale trials should be undertaken in developing countries to:
- Make potential users aware of the availability of emulsion technology.
- Demonstrate the compatibility of the emulsion with distillate and existing diesel engines.
- Demonstrate that emulsion fuels can be used with no impairment to the performance of diesel engined equipment.

Such trials should have the following features:
- Undertaken in a country with an indigenous ethanol supply (e.g. Malawi, Thailand, Brazil).
- Comprise a mixed fleet of automotive, agricultural and earth moving equipment totalling 30 to 50 units. These units should be based within a limited area of 20 km radius and have an operating range of 50 km. A further 5 to 10 mixed units should be tested concurrently on 100% distillate to serve as controls.
- Adequate field workshop facilities should be available for on site unit maintanance. Any part failures should be evaluated by both the original manufacturer and an independant assessor.
- Adequate emulsion blending facilities and storage should be centrally located in the test area.
- Supervision and monitoring of the trial should include:
  a. Regular measurement of engine power.
  b. Constant measurement of fuel consumption.
  c. Regular sampling of engine oil.
  d. Keeping of a maintanance log.
  e. Good record keeping of all aspects of the trial.
- The trial should extend for a minimum period of one year.
- Visits by senior government officials of other developing countries to observe the trials should be encouraged.

Such trials would put to rest the fears and doubts concerning this "new fuel" that will inevitably exist.

* Further research should be carried out in the area of ignition improvers with special emphasis on :
  - Increasing the effectiveness of TEGDN.
  - Establishing the effect of TEGDN in emulsions containing low ignition quality distillates.
  - Determining the effect of emulsions containing ignition improvers on exhaust emissions.

# 8. APPENDICES

## 8.1. Engine Results Curves

| FIG | Title | | |
|---|---|---|---|
| AP1 | Repeatability of Needle Lift and Cyl. Pressure | DIST 100 | 2000 rpm |
| AP2 | " | " | 1400 " |
| AP3 | " | " | 800 " |
| AP4 | " | " | IDLE |
| AP5 | " | E20 | 2000 rpm |
| AP6 | " | " | 1400 " |
| AP7 | " | " | 800 " |
| AP8 | " | " | IDLE |
| AP9 | " | E20/2.6TEGDN | 2000 rpm |
| AP10 | " | " | 1400 " |
| AP11 | " | " | 800 " |
| AP12 | " | " | IDLE |
| AP13 | " | E20/5.2TEGDN | 2000 rpm |
| AP14 | " | " | 1400 " |
| AP15 | " | " | 800 " |
| AP16 | " | " | IDLE |
| AP17 | " | E20/0.2ION | 2000 rpm |
| AP18 | " | " | 1400 " |
| AP19 | " | " | 800 " |
| AP20 | " | " | IDLE |
| AP21 | " | E20/0.4ION | 2000 rpm |
| AP22 | " | " | 1400 " |
| AP23 | " | " | 800 " |
| AP24 | " | " | IDLE |
| | Effect of TEGDN on Start of Injection, Combustion, Max. Pressure and Pressure Rate v rpm | | |
| AP25 | DIST 100, E20, E20/2.6TEGDN, E20/5.2TEGDN | Full load | |
| AP26 | " | 2/3 load | |
| AP27 | " | 1/3 load | |
| | Effect of ION on Start of Injection, Combustion, Max. Pressure and Pressure Rate v rpm | | |
| AP28 | DIST 100, E20, E20/0.2ION, E20/0.4ION | Full load | |
| AP29 | " | 2/3 load | |
| AP30 | " | 1/3 load | |
| | Effect of TEGDN on Start of Injection, Combustion, Max. Pressure and Pressure Rate v Torque | | |
| AP31 | DIST 100, E20, E20/2.6TEGDN, E20/5.2TEGDN | Full load | |
| AP32 | " | 2/3 load | |
| AP33 | " | 1/3 load | |

| FIG | Title | | |
|---|---|---|---|
| | Repeatability of Needle Lift and Cyl. Pressure | | |
| AP53 | 20 deg BTDC | DIST 100 | 2000 rpm |
| AP54 | " | " | 1400 " |
| AP55 | " | " | 800 " |
| AP56 | " | " | IDLE |
| AP57 | 14 deg BTDC | " | 2000 rpm |
| AP58 | " | " | 1400 " |
| AP59 | " | " | 800 " |
| AP60 | " | " | IDLE |
| AP61 | 26 deg BTDC | " | 2000 rpm |
| AP62 | " | " | 1400 " |
| AP63 | " | " | 800 " |
| AP64 | " | " | IDLE |
| AP65 | 20 deg BTDC | E20/3.9TEGDN | 2000 rpm |
| AP66 | " | " | 1400 " |
| AP67 | " | " | 800 " |
| AP68 | " | " | IDLE |
| AP69 | 14 deg BTDC | " | 2000 rpm |
| AP70 | " | " | 1400 " |
| AP71 | " | " | 800 " |
| AP72 | " | " | IDLE |
| AP73 | 26 deg BTDC | " | 2000 rpm |
| AP74 | " | " | 1400 " |
| AP75 | " | " | 800 " |
| AP76 | " | " | IDLE |
| | Long Term DIST 100 Repeatability of Start of : Injection, Combustion, Max. Pressure and Pressure Rate v rpm | | |
| AP77 | " | | Full load |
| AP78 | " | | 2/3 load |
| AP79 | " | | 1/3 load |
| | Effect of Static Timing on Ignition Delay, Max. Pressure and Pressure Rate v rpm | | |
| AP80 | 14 deg, 20 deg, 26 deg BTDC | DIST 100 | Full load |
| AP81 | " | " | 2/3 load |
| AP82 | " | " | 1/3 load |
| AP83 | " | E20/3.9TEGDN | Full load |
| AP84 | " | " | 2/3 load |
| AP85 | " | " | 1/3 load |

| FIG | Title | | |
|---|---|---|---|
| | Repeatability of Needle Lift and Cyl. Pressure | | |
| AP108 | 18 deg BTDC | DIST 100 | 2000 rpm |
| AP109 | " | " | 1400 " |
| AP110 | " | " | 800 " |
| AP111 | " | " | IDLE |
| AP112 | " | E25/3.9TEGDN | 2000 rpm |
| AP113 | " | " | 1400 " |
| AP114 | " | " | 800 " |
| AP115 | " | " | IDLE |
| | Effect of TEGDN on Start of Injection, Combustion, Max. Pressure and Pressure Rate v rpm | | |
| AP116 | DIST 100, E25/3.9TEGDN | 18 deg | Full load |
| AP117 | " | " | 2/3 load |
| AP118 | " | " | 1/3 load |
| | Effect of TEGDN on Ignition Delay, Max. Pressure and Pressure Rate v Torque | | |
| AP119 | DIST 100, E25/3.9TEGDN | " | 2000 rpm |
| AP120 | " | " | 1400 " |
| AP121 | " | " | 800 " |
| | Effect of E25/3.9TEGDN Emulsion on Injection Pump Delivery, Torque and S.F.C. | | |
| AP122 | DIST 100, E25/3.9TEGDN | " | Full load |
| | Effect of E25/3.9TEGDN Emulsion on Injection Pump Delivery, Efficiency and S.F.C. v Torque | | |
| AP123 | DIST 100, E25/3.9TEGDN | " | 2000 rpm |
| AP124 | " | " | 1400 " |
| AP125 | " | " | 800 " |