EXECUTIVE SUMMARY.

ALCOHOLS AS FUELS FOR UNMODIFIED DIESEL ENGINES

* The use of alcohols as extenders of gasoline fuels has led to significant implementation of "gasohol" in several countries (e.g. Brazil).

* The ratio of distillate to gasoline usage in developing countries is such that an extender for distillate is far more necessary than an extender for gasoline.

* Distillate is an income producing fuel having a vital role to play in the agricultural, goods and product transportation and industrial sectors thus further strengthening the need for a suitable extender.

* A number of countries have surplus ethanol or the capacity to produce ethanol and could significantly achieve foreign exchange savings from substituting domestically produced ethanol for imported crude oil or refined distillate.

* Ethanol production for fuel is labour rather than capital intensive and provides real opportunity for effective decentralisation in developed nations and a strong base for third world countries.

* While the technology for mixing hydrated ethanol with gasoline is relatively straightforward, in the past it has not been possible to produce an economical stable blend of hydrated ethanol and distillate, i.e. "diesohol".

* Apace Research Ltd. has developed an effective distillate/alcohol emulsifier technology that, for the first time, enables the practical and economical blending of hydrated alcohols (both ethanol and methanol) with distillate and the use of these diesohhols in existing, unmodified diesel engines.

* The level of ethanol substitution that can be readily achieved is:

15% ethanol	- No engine modifications or ignition improver required.
25% ethanol	- No engine modification required, fuel and/or timing re-adjustment may be desirable. Ignition improver required.
30% ethanol	- No engine modification needed in majority of cases, however some fuel injection equipment may require modification. In some cases new fuel injection equipment will be required leading to possible engine changes.

Ethanol substitution in excess of 30% is not recommended for unmodified existing diesel engines.

At the 15% substitution level rapid and flexible implementation of a diesohol technology is possible and can be followed by the gradual introduction of higher substitution levels.

* Patents have been granted for the technology in five countries, including the United States and Australia, and futher patent applications are pending in 30 other countries.

* Agreements have been made with two major international companies - Albright & Wilson Limited and Shell Internationale Research Maatschappij B.V. (Shell).

  Albright & Wilson has been granted a world-wide non-exclusive licence to produce and market the Apace emulsifier and diesohols.

  Shell has been granted a world-wide licence to undertake a research and development programme covering optimisation of diesohols.

  Shell has also been granted the right of first refusal to the second world-wide non-exclusive licence to commercially produce and market the Apace emulsifier and diesohols.

ABSTRACT

The thermodynamic performance of a FORD 3000 diesel engine was evaluated on an engine test bed using stable ethanol/distillate emulsions containing varying proportions of different ignition improvers. Additionally a limited road test using a Toyota Landcruiser was also performed.

It has been previously shown that increasing the alcohol content of an alcohol/distillate blend (including emulsion) decreases both the ignition quality (cetane number) and the calorific value of such a blend. In a diesel engine the effect of the former leads to knock or quench but can increase the thermal efficiency, while the latter results in a power drop.

Previous tests and subsequent discussions with major engine manufacturers have indicated that an ethanol/distillate emulsion containing 20% by volume ethanol without ignition improving additives is extremely marginal as far as ignition delay and knock are concerned. In fact engine manufacturers would not approve the use of an emulsion containing in excess of 15% v/v ethanol without ignition improving additives.

The purpose of this project was to evaluate ignition improving additives of two types, one which enhances the ignition quality of the continuous distillate phase, the other affecting only the dispersed alcohol phase. Also investigated was the effect of variations in injection timing and establishment of the optimum timing for an ethanol emulsion.

The results obtained have shown that the alcohol compatible ignition improver Triethyleneglycoldinitrate (TEGDN) is extremely effective in reducing ignition delay and knock throughout the engine speed and load range. The cold starting characteristics of the Toyota Landcruiser were also substantially enhanced. The quantity required was only 75% of that recommended by the supplier for use with ethanol as the sole fuel in diesel engines and it may be beneficial to reduce this quantity even further in order to achieve improved thermal efficiency.

The timing changes showed that as far as engine performance was concerned there was minimal difference betweeen the distillate and emulsion containing TEGDN in terms of power, thermal efficiency, ignition delay and combustion pressure characteristics. Retarding the timing improved the performance of the engine on both fuels. There was however a dramatic increase in observed smoke on distillate with retarded timing which was not evident on the ethanol/ distillate emulsion.

It should be noted that most engine manufacturers set the timing slightly advanced and sacrifice some performance for smoke free exhaust. The timing using the emulsion could therefore be set to the optimum and some of the loss of performance due to the lower calorific value regained.

ETHANOL/DISTILLATE EMULSIFIED BLENDS IN DIESEL ENGINES.

An Evaluation of Diesel Engine Performance when Fuelled by Surfactant Stabilised Hydrated Ethanol/Distillate Emulsions containing Ignition Improving Additives.

1. INTRODUCTION

Apace Research Ltd. (A.R.L.) is a non profit company concerned with the research and development of renewable energy technologies mainly in the biomass sector. It is especially involved in the production and application of alcohols with emphasis on fuels for diesel engines.
The company competes for research funds from governments and the private sector and in addition has a capacity for internally funded research in these and other areas.

A large proportion of the R.& D. as well as marketing effort of A.R.L. to date has been directed towards developing energy efficient means of production and utilisation of the alcohols, ethanol and methanol. The reasons for encouraging the implementation of fuel alcohol industries/utilisation include :

* Concern over guarantee of supply of distillate and it's cost.

* Alcohol production is strongly linked to the agricultural base. Because of economic limitations imposed by the transport of large quantities of biomass feedstock, alcohol for fuel production is effectively a labour intensive industry and provides real opportunity for effective decentralisation in developed nations and a strong base for third world countries.

* Compared to coal and oil shale conversion to synthetic hydrocarbon fractions, alcohol production is not capital intensive. Furthermore, in the case of methanol produced from non-renewable resources, i.e. natural gas or coal, it's cost is already competitive with petroleum based fuels. Methanol is also available as a by-product from coal or natural gas to synthetic gasoline processes, for example Sasol and Mobil processes respectively, and hence could readily be utilised as both a gasoline and distillate extender.

* When produced from biomass, fuel alcohol does not result in cumulative increase of atmospheric carbon dioxide.

* In order to avoid competition for land for food production, more effective land utilisation and the development of integrated, multi-purpose agriculture and horticulture will be encouraged.

* In a broad view, alcohol is a valuable feedstock for the chemical industry generally.

In the applied sense, the research effort of A.R.L. has been directed towards resolving three major criticisms of the fuel alcohol industry. These are :

* The absence of a cost and performance effective method of using alcohols in diesel engines.
* In relation to ethanol for fuel, the high processing energy requirement of conventional technology, in particular that of distillation, often results in an overall negative energy balance for the fuel.
* The lack of a low cost and effective waste treatment process for fermented biomass.

While patent applications have resulted from work in all three areas the main marketing effort to date has concerned the A.R.L. technology for extension of distillate with alcohols. That technology also constitutes the subject of the UNIDO funded project reported here.

2. EXTENSION OF DIESEL FUELS WITH ALCOHOLS

2.1 Background.

Since even hydrated methanol or ethanol are easily made miscible with gasoline, such blends received world-wide attention and in several countries significant "gasohol" programmes are under way.

However, because of a number of hitherto technical difficulties, the widespread use of alcohols in diesel engines has not been realised. This has created impediments to future fuel alcohol industries in a number of ways :

Studies on the economic feasibility of alcohol fuels have been limited to considering the use of alcohols in the gasoline market only.

Because of increasing demand for distillate world-wide, and because of the relatively inflexible ratio of gasoline to distillate in the refining operation, cracking to satisfy distillate demand results in gasoline surplus or lower quality distillate. If alcohol substitution occurs only in the gasoline market the refinery balance is further aggravated.

Since the great bulk of fuel consumed by income producing activity is distillate, alcohols have, by default given added importance to other alternatives exclusively for distillate, such as esterified vegetable/ animal oils/fats.

However it should be recognised and stressed that for the gasoline and distillate markets a common extender for either market as the situation demands is highly desirable.

A.R.L. has developed a technology which enables the practical and economic blending of hydrated alcohols and distillate and the use of such blends in unmodified existing diesel engines.

The commercial value and importance of this inherently simple concept and technology lies in its potential benefits for a broad spectrum of interests :

At a national level, the direct substitution of domestically produced alcohols, from whatever source, for imported petroleum products, benefits through savings in foreign exchange. In this context it is also important to note that falling or low world crude oil prices can result in increasing domestic consumption, which can aggravate balance of payments, particularly for those countries heavily dependent on the importation of refined or crude petroleum products.

By allowing for a market to be created for methanol as a liquid transport fuel, the A.R.L. technology can give added incentives and markets for major coal and/or gas resource development projects which may be suffering a downturn in their more traditional markets.

Considering petroleum refining operations, even in the short term, indications are that critical problems of refinery balance and efficiency of operation will be encountered due to a rapidly increasing market demand for distillates and lead free gasolines,and the falling quality of crude cracking stock for their production. The ability to offset this trend by the substitution of alcohols for distillates is thus of considerable significance and value to refinery practice. Further the ability to extend the automotive distillate market sector with alcohol may allow the refineries to produce more aviation turbine fuel without greatly upsetting the gasoline-distillate balance at the refinery. Alternately, should the local demand and refinery practice be such that the shortage is in the gasoline rather than the distillate sector then "gasohol" can be easily produced.

2.2 Technology Description and Research and Development Rationale.

Opportunities to use methanol or ethanol directly as distillate extenders, as opposed to their indirect use in esterified vegetable oils, continue to arise on both local and national levels as a reflection of changing socio-economic circumstances, and out of foreign exchange savings considerations.

At the present stage of implementation of alternative fuels however, such opportunities , and the optimum level of alcohol substitution are often the subject of particular sets of circumstances which in themselves are subject to change.

Thus, maximum flexibility in the level of alcohol substitution is an important consideration when assessing the known methods of achieving alcohol substitution in existing diesel engines in particular.

In general terms, the current methods of achieving alcohol substitution in diesel engines involve modification of the fuel to suit the engine, modification of the engine to suit the fuel, or a combination of both. The methods are conveniently summarised in Table 1. (Page 9)

Alcohol cannot be used as the fuel in compression ignition (diesel) engines because the high self ignition temperature and high latent heat of vaporisation result in unacceptable ignition delay leading at best to severe knock and at worst quench (no ignition at all) without the use of ignition improvers. Changes are almost certainly required to the fuel injection system and lubricants need to be added to the alcohol.

However, when considering the introduction of alcohol extended transport fuels into the established infrastructure, blends to about 15% by volume of alcohol are usually of prime interest. As to the available choices of achieving at least this level of substitution, there is a choice of two approaches. These are -dual fuel systems or blended fuels.

In the dual fuel system, alcohol and distillate are kept in separate tanks and metered to the engine via separate arrangements. A control system is employed to limit the amount of alcohol admitted to the combustion chamber under those conditions where extended ignition delay would otherwise occur. Such systems have been shown to work, but the costs to retrofit existing engines are considerable, and there is the added complication of fuelling with two different fuels. Additionally the resale value of such vehicles can be substantially reduced if on resale it is moved to an area where no alcohol is available as an extender.

The blended fuel approach incorporates modifying the fuel so that little or no modifications are required to the engine or fuel injection equipment. From the user point of view this is by far the best approach.

Further, in relation to strategy and programme for the introduction of fuel alcohols into the established transport infrastructure it should also be noted that an advantage of the blended fuel aproach is that the successful use in engines of blends containing in excess of 15% by volume alcohol requires the incremental addition to such blends of a suitable ignition improver with possible progressive fuel injection equipment and engine adjustments or modifications.

Thus in this way, with existing diesel engine population, the blended fuel approach allows for progressively higher levels of alcohol substitution coincident with alcohol availability, while still retaining a high degree of flexibility in relation to engine fuelling.

The obvious starting point for the blended fuel approach is to mix hydrated alcohol and distillate together in one tank and then assess engine performance when running on the mix.

Unfortunately, although strictly anhydrous ethanol and distillate are miscible at high temperatures, the presence of even 0.05%(v%) water in the mixture causes phase separation. Since even so called "anhydrous alcohol" often contains at least 0.5% (v%) water it is virtually impossible to obtain a homogeneous mixture of ethanol and distillate. Further even strictly anhydrous methanol is immiscible with distillate.

One method of overcoming this problem is to form an emulsion of the ternary system alcohol/distillate/water by use of chemical emulsifiers.

To this end A.R.L. has developed a new surfactant for producing emulsions of such ternary systems which in addition to producing long term stable emulsions is also economical in use and environmentally acceptable. It also exhibits compatibility with distillate only operation and high tolerance to water ingress.

The precise composition of the surfactant is still proprietary but it essentially consists of a mixture of a poly (ethyleneglycol-styrene) copolymer and a poly(butadiene -styrene) copolymer. Thus only the elements carbon,hydrogen and oxygen are present.

In terms of physical chemistry of the emulsions, there are two types:

> Alcohol/water as the dispersed phase in a continuous phase of distillate, termed EW/D,
>
> Distillate as the dispersed phase in a continuous phase of of alcohol/water, termed D/EW.

The preferred type for a number of reasons is the EW/D type.

The structure of the emulsions also allows other additives, such as ignition or combustion improvers, which are compatible with either the distillate or the alcohol phases to be incorporated into the emulsions. This broadens considerably the range of additives available.

General criteria used in the development of A.R.L. "diesohols" are on two fronts , commercial and physical, as follows.

Table 1. COMPARISON OF CURRENTLY AVAILABLE METHODS FOR ACHIEVING SUBSTITUTION IN EXISTING DIESEL ENGINES

% ALCOHOL SUBSTITUTION

0 10 20 30 40 50 60 70 80 90 100

BLENDED FUEL APPROACH (Modification of alcohol fuel to suit the existing diesel engines)	DALCO CHEMICAL EMULSION	Low cost, Unmodified engines Compatible with diesel only engine operation. Water tolerant
	DALCO CHEMICAL EMULSION PLUS IGNITION/CETANE IMPROVER	Increasing engine modification required Decreasing compatibility with diesel only operation Increasing engine development costs Water tolerant over whole range
DUAL FUEL AND MECHANICAL MODIFICATION APPROACH (Modification of existing diesel engines to suit alcohol fuel)	MECHANICAL EMULSION	Installation needs comprehensive mods to fuel system. High installation costs.
	MECHANICAL EMULSION PLUS IGNITION/CETANE IMPROVER	As for chemical emulsion plus ignition/cetane improver Complication of fuelling with two different fuels
	ASPIRATION	Complicated engine and fuel injection equipment modifications required. Can be compatible with diesel only operation. High engine development costs. Complications of fuelling with two different fuels.
	DUAL INJECTION	As for aspiration, at greater cost but gives superior performance. Alcohol fuel may require lubricant additive.
	SPARK IGNITION SYSTEMS	Not compatible with diesel only engine operation. Fuel may require lubricant additive. High engine development costs.

2.3 Commercial suitability criteria:

- To enable the use of lower cost hydrated alcohols containing to at least 10% by volume water.

- The contribution to the cost of diesohols due to surfactant and its incorporation to be relatively insignificant. The A.R.L. method of preparation of diesohols is as follows:

  A surfactant concentrate is prepared and then metered in the correct proportion with likewise metered quantities of distillate and hydrated alcohol and passed through an in-line, high shear mixer or low pressure ultrasonic homogeniser to achieve a dispersion of hydrated alcohol in distillate.

- Total surfactant concentration to be less than 1% (w/v) (i.e. less than 10 grams per litre of blend).

- The raw materials for the manufacture of the compounds comprising the surfactant to be common, widely available and low cost.

2.4 Physical suitability criteria:

- On storage, which ensures minimum loss of ethanol by evaporation, stability towards phase separation to be in excess of 12 months.

- To be suitable for use in existing diesel engines and require no or minimal modifications to be made to the engine or fuel injection system. Also the EW/D type "diesohols" to be miscible with distillate in any proportion.

- An absolute viscosity not largely different from that of automotive distillate (2.5-3.5 centipoise @ 38 deg C).

- To be physically stable at high pressure and temperature. This is particularly relevant to the high volume of return line fuel which characterises particular types of fuel injection systems. Portion of such fuel has been subjected to the maximum operating pressure and temperature of the fuel prior to return to the fuel tank.

- Hydrated alcohols have poor lubricating qualities. An EW/D emulsion reduces the risk of increased corrosion/erosion of mechanical parts by hydrated alcohol.

- The surfactant not to adversely affect any mechanical components, lubricating oil, etc.

- The surfactant not to release unacceptable pollutants upon combustion.

3. PROJECT DESCRIPTION.

3.1 Project objectives.

This UNIDO funded project furthers the work already carried out by Apace Research Ltd. to establish the feasibility of extending distillate fuel supplies by the addition of ethanol, especially in developing countries.

Prior work by Apace was aimed at establishing the ethanol substitution level possible without the use of ignition improvers. It was concluded that, on the engines then tested, 20% substitution was the limit. Since then, however, further testing with different engines reduced this level to approx. 15%. This lower figure is more acceptable to engine manufacturers.

The objective of this project was to establish the maximum level of ethanol substitution possible, by the addition of suitable ignition improvers to emulsions to reduce the degree of knock and quench resulting from the use of ethanol in excess of 15% , without incurring high fuel or engine modification costs.

3.2 Project Work Program

* Establish the effect of different types of ignition improvers on the thermodynamic performance of a suitably instrumented diesel engine (specifically a FORD 3000) mounted on a test bed and connected to a dynamometer.

* Establish the optimum injection timing for the emulsion fuels.

* Establish the maximum economic level of alcohol substitution possible for existing unmodified diesel engines.

* Perform chassis dynamometer testing and road trials in a suitable vehicle.

3.3 Main Findings and Main Conclusions

Two commercially available ignition improvers were tested, one (Isooctyl nitrate (ION)) is already widely used to improve the ignition quality of distillate, and the other (Triethyleneglycoldinitrate (TEGDN)) is specifically formulated for use in diesel engines modified for 100% ethanol.

It was found that ION did not reduce ignition delay and knock to any great extent when used in the recommended quantities (0.2 -0.4% of the emulsion) but projections show that somewhere around 0.8- 1.0% could give acceptable results in a 20% emulsion.

The product containing TEGDN supplied for evaluation,"Alcoolita", also contained dibutylphalate and diphenylamine as stabilisers (present to ensure product safety), castor oil,other lubricants and an anti-corrosive agent.
The quantity of TEGDN alone required for acceptable engine performance is 3.1% of the alcohol content of the emulsion. Therefore the percentage needed for, say, a 25% emulsion would constitute 0.78% of the total emulsion volume.

3.4 Diesel engine thermodynamic performance.

The assesment of engine thermodynamic performance was based mainly on the following criteria:

* Maximum cylinder pressure
* Maximum rate of change of cylinder pressure
* Ignition delay i.e. the number of degrees of crankshaft rotation occurring between start of injection and start of combustion.

Torque, Power, Specific fuel consumption and Thermal efficiency are considered of secondary importance in this instance, however they were not ignored.

Maximum cylinder pressure.

The maximum pressure reached in a cylinder during combustion is mainly determined by the applied load and injection timing with the emulsion alcohol content having only minor effects. Table 2. shows this quite clearly where for example at 20 deg static timing the difference in cylinder pressure between the two extreme fuels (these being emulsion + 0.62% TEGDN and 20% ethanol emulsion) is only 1.2 bar at full load whereas a change in timing of six degrees causes a change in pressure obtained with distillate in excess of 6 bar. The effect of the different fuel type on engine cylinder pressure is more significant at lower applied loads but of course the pressures are also much lower. An example of "tailoring" the maximum cylinder pressures of an alcohol emulsion is also shown where almost identical cylinder pressures are achieved throughout the load range for distillate at 20 degrees and 25% ethanol emulsion containing 0.78% of TEGDN at 18 degrees static timing.

Maximum rate of change of cylinder pressure.

At any given engine speed this is dependent on

* Ignition quality of the fuel
* Dynamic injection timing
* Applied load

and is probably the most important of the thermodynamic criteria. Too high a rate can result in a destructive knock condition whereas too low a rate will lead to an inefficient thermodynamic cycle.

Table 3 shows the relationship between the various factors. The inter-relationship is quite complex. In the example selected a 12 degree change in timing changes the rate from 19.1 to 11 bar/deg under full load conditions on distillate which is equivalent to a reduction of 42.6%. A load change from full load to 1/3 load at 20 deg using the same fuel reduces the rate by 47%. The highest rates of pressure rise are obtained using the E20 emulsion with no ignition improvers. The addition of TEGDN to the 20% emulsion has the effect of modifying the ignition quality, as far as rate of pressure rise is concerned, to being almost equivalent to that of distillate. The E25/TEGDN at 18 deg BTDC exhibits a lower rate of pressure rise at full load, however part load match with distillate at 20 deg is very close.

TABLE 2. Maximum cylinder pressure (bar)

STATIC TIMING	14 deg		20 deg			26 deg		18 deg
LOAD	DIST	TEGDN	DIST	E20	TEGDN	DIST	TEGDN	E25/TEGDN
Full	89.8	88.6	96.2	97.1	95.9	103	102	96.9
2/3	66.8	69.6	75.4	78.8	76.7	85	85	75
1/3	56.6	51.6	61.4	65.3	60.5	67	66	61

Notes: Static timing is expressed in degrees BTDC.
DIST = 100% automotive distillate
E20 = Emulsion containing 20% v/v hydrated ethanol and no ignition improvers.
TEGDN= Emulsion containing 20% v/v hydrated ethanol where the alcohol contains 3.1% TEGDN.
E25/TEGDN= Emulsion containing 25% v/v hydrated ethanol where the alcohol contains 3.1% TEGDN.
LOAD = These are nominal loads only, and FULL, 2/3 and 1/3 are for identification only, however part loads are identical for all fuels. Thus 2/3 load is the same for any speed, fuel or timing test condition.

Results apply to an engine speed of 1400 rpm.

TABLE 3. Maximum rate of cylinder pressure rise (bar/deg)

STATIC TIMING	14 deg		20 deg			26 deg		18 deg
LOAD	DIST	TEGDN	DIST	E20	TEGDN	DIST	TEGDN	E25/TEGDN
Full	11	10.8	15.7	22.2	15	19.1	20.2	14.2
2/3	8.2	8.3	10.7	13.7	9.9	14.1	14.5	11
1/3	6.8	4.5	8.3	10.2	6.9	9.6	8.9	7.2

Notes: As per Table 2.

Ignition delay.

There is a tendency by most other researchers into thermodynamic behaviour to express the ignition delay in terms of time only, this being taken from the point of commencement of injection (as determined by needle lift diagrams) and commencement of combustion (determined by the inflection of the cylinder pressure curve). Although the Apace equipment has the ability to determine these times, we believe that the sensitivity of the delay expressed in terms of degrees is greater than in terms of time alone. Thus the results on which decisions can be made have been based on the degree mode.
As Table 4 shows the ignition delay is mainly affected by injection timing (over the 12 degree range). The load has very little effect at more retarded timings, but has a significant effect at the more advanced timings. The ignition quality of the fuel also has a major bearing on the ignition delay.

TABLE 4. Ignition delay (Crank angle degrees).

STATIC TIMING	14 deg		20 deg			26 deg		18 deg
LOAD	DIST	TEGDN	DIST	E20	TEGDN	DIST	TEGDN	E25/TEGDN
Full	8	7.8	10.1	11.6	9.7	12.4	12.0	8.8
2/3	8	8	8.9	10.4	8.8	10.9	10.4	8.5
1/3	8.4	8.8	9.2	9.8	8.1	10.8	9.2	8.3

Notes: As per Table 2.

On the basis of the results presented in Tables 2,3 and 4 it can be seen why 18 deg timing was chosen for the E25/TEGDN emulsion to achieve similar power output to the 20 deg distillate timing. Table 5 shows the torque (and hence the power) attained under the various conditions. Although the calorific value of the E25/TEGDN emulsion is reduced to 37.66MJ/kg from 42.75MJ/kg for distillate (an 11.9% drop) the torque is actually decreased by only 3.2% (This is fairly typical throughout the speed range). Similar results can be applied to the TEGDN emulsion(20% v/v ethanol where the alcohol contains 3.1% of TEGDN) and 14 deg timing where the reduction is even less.

It should be noted that because of smoke emissions the engine could not be operated normally at 14 deg static timing on distillate and therefore comparison must be made to the 20 deg timing. The emulsions are reasonably smoke free at the retarded conditions and could be operated at the 14 deg setting.

TABLE 5. Observed engine torque (NM)

STATIC TIMING	14 deg		20 deg			26 deg		18 deg
LOAD	DIST	TEGDN	DIST	E20	TEGDN	DIST	TEGDN	E25/TEGDN
Full	166	159	160	148	152	142	142	155

Notes: As per Table 2.

Thermal efficiency.

The thermal efficiency is dependent in the main on the start of combustion, rate of pressure rise and the completeness of combustion. The most efficient heat cycle is the constant volume cycle and the closer the approch to this ideal the higher the thermal efficiency. That an emulsion containing no ignition improvers (such as the listed E20) should exhibit higher thermal efficiency can be readily explained by the first two factors i.e. later start of combustion and higher rate of pressure rise. The same cannot be stated for the E20 emulsion containing TEGDN and thus any efficiency improvement must be attributed to improved combustion.

Table 6. sets out the efficiencies obtained under the various conditions and it can be discerned that again injection timing plays a significant role as does the fuel type. The typical characteristic indicating that the highest efficiency is obtained somewhere between 55 and 80% of full load is also very much in evidence under all conditions.

TABLE 6. Thermal efficiency (%)

STATIC TIMING	14 deg		20 deg			26 deg		18 deg
LOAD	DIST	TEGDN	DIST	E20	TEGDN	DIST	TEGDN	E25/TEGDN
Full	27.4	29.2	26.5	27.6	27.5	23.4	25.8	28.5
2/3	30	30.5	29.7	29.3	29.4	27.9	28.3	29.6
1/3	20.4	20.2	21.5	20.6	20.1	19.2	20.4	20.4

Notes: As per Table 2.

Specific fuel consumption.

The thermal efficiency of the engine heat cycle and calorific value of the fuel determine the specific fuel consumption.
Table 7. lists the values of the specific fuel consumptions obtained and the interaction of efficiency and calorific values observed. Thus it can be seen that 100% distillate because of its high calorific value tends to exhibit the lowest specific

fuel consumption even when its efficiency is low compared to the emulsions. Where the efficiencies between the fuels are similar (as at part loads) then specific fuel consumption must increase in direct relationship to the calorific value of the fuel. This is further adversely compounded by the density of the fuel as most operators use volumetric instead of gravimetric fuel consumption criteria.

TABLE 7. Brake specific fuel consumption. (BSFC gms/KW/hr)

STATIC TIMING	14 deg		20 deg			26 deg		18 deg
LOAD	DIST	TEGDN	DIST	E20	TEGDN	DIST	TEGDN	E25/TEGDN
Full	307	319	289	336	338	360	361	335
2/3	281	306	281	317	317	301	329	323
1/3	412	462	410	450	464	439	456	470

Notes: As per Table 2.

Toyota Landcruiser experience.

The Toyota vehicle fitted with a 6 cylinder H series indirect injection engine was down on power when operated on a 20% ethanol emulsion containing .62% v/v TEGDN. The power could be readily restored by fuel rack adjustment only, rather than carrying out timing alterations. This would, obviously, increase the fuel consumption to compensate for the reduced calorific value of the fuel.

Observations made of the cold starting ability indicated that cold starting was much easier using the emulsion fuel with ignition improver than with distillate. Apart from the fact that the glow plugs needed to be used for a shorter period there was an almost total lack of cold start "crackle" (knock) and black smoke from the start-up excess fuel.

Driving the vehicle normally on the road did not reveal any necessity for re-establishing the power output, the engine operated smoothly throughout the load and speed range. At no time was any black smoke emitted.

3.5 Conclusions on the results obtained

It would be inappropriate to make any firm recommendations based on the results obtained. However it can be stated with reasonable confidence that 20%, probably 25% in the vast majority of cases and in certain applications (such as large stationary or railway engines) even 30% ethanol substitution can be achieved.

The scenarios envisaged are :

* 15% ethanol substitution- No engine modifications and no ignition improver required.
* 20% ethanol substitution- No engine modifications required, but some fuel delivery or timing changes may be required. Ignition improver required.
* 25% ethanol substitution- No engine modifications required in majority of cases, but fuel delivery and/or timing changes will be required. Ignition improver required.
* 30% ethanol substitution- No engine modifications required in majority of cases however some fuel injection equipment may need to be modified. In extreme cases new fuel injection equipment will be required- leading to possible engine changes. Ignition improver required.
* Ethanol substitution in excess of 30% would not be recommended as fuel injection equipment modifications would be required in virtually all cases. The ethanol/distillate emulsion may also require lubricant in addition to ignition improver and emulsifier.

4. POTENTIAL FOR INDUSTRIAL/COMMERCIAL APPLICATION.

The apparent stability and oversupply of crude oil existing at present would seem to indicate that the emulsion technology would have limited application. However the quality of the available crude is dropping rapidly and the need for additional cracking and refining for the lead-free gasoline market as well as the demand for high grade (and highly profitable) aviation kerosene is eroding that part of the barrel generally sourcing the automotive type distillate. There is already evidence of quite serious down-grading in terms of the ignition quality of automotive distillate which is being boosted by the addition of ignition improvers. To this state of affairs must be added the plight of the alcohol (either ethanol or methanol), sugar and starch producers which is causing a serious glut of alcohol in the market place. This situation will not be improved when the Middle East mega-litre methanol plants come on stream in the near future.

Distillate can be considered as an income producing product having a vital role to play in the agricultural, industrial and goods/product transportation sectors. This is especially true in developing countries where the ratio of distillate to gasoline consumption is high. The cost of distillate to these countries is very high (at the time of writing the strength of the American dollar was having a significant effect on these costs) and thus the introduction of emulsions incorporating indigenously produced alcohol could alleviate balance of payment problems.

It is the opinion of the authors that there are a number of countries at present where socio-economic conditions are such that great benefits would accrue rapidly from the introduction of the emulsion technology.

Apace Research Ltd. has filed complete patent specifications relating to the emulsion technology in the following countries.

Australia	U.S.A.	Europe
Argentina	Colombia	designating
Mexico	Chile	Austria
Norway	India	Belgium
South Africa	Mauritius	France
Israel	New Zealand	Federal Republic of Germany
Japan	Republic of China(Taiwan)	Italy
Philippines	Sri Lanka	Liechtenstein
Indonesia	Nigeria	Luxembourg
Canada	Pakistan	Netherlands
Brazil	Republic of Korea	Sweden
Venezuela	Thailand	Switzerland
Turkey		United Kingdom

with confirmation applications to be filed in:

Kenya
Malaysia
Singapore
Fiji

Negotiations in relation to licensing the technology have culminated in the granting of a world-wide non-exclusive licence to Albright and Wilson Ltd.(UK), a major international chemical company, to manufacture, use and sell the emulsifier and the emulsions.
The right of first refusal for the second such licence has been granted to Shell (Netherlands).

Governments and/or organisations interested in implementing the technology should contact either or both of these organisations.

5. ENGINE PERFORMANCE TESTS.

5.1 TEST ENGINES.

All preliminary test work to establish the effect of the selected ignition improvers was conducted on a Ford 3000 engine located in the Engineering Department at Hawkesbury Agricultural College.

This engine was considered to be suitable for this type of work for a number of reasons, the main ones being:

a. It was used on previous methanol projects and has proved itself tolerant to a considerable degree of abuse (i.e. knock).

b. A complete engine is available as a spare, including Fuel Injection Pumps and Injectors. Spare parts are available locally at reasonable cost.

c. The combustion chamber is not state of the art design and thus should be relatively sensitive to fuel quality. A bore to stroke ratio of 1:1 is used and cylinder volume is around the 1 litre capacity. Max governed speed is 2200 r.p.m. although 2000 r.p.m. was considered more suitable for the tests. A full specification for this engine is listed in Table 8.

Table 8.

Specification for Ford 3000 Test Engine.

Make	Ford
Model	3000
Type	4 stroke,direct injection, naturally aspirated.
No. of cyl.	3
Bore	106.7 mm (4.2")
Stroke	106.7 mm (4.2")
Displacement	2860 cc (174.5 cis)
Comp. Ratio	16.5:1
Firing Order	123
Max. No Load Speed	2175-2225 r.p.m.
Idle Speed	600-700 r.p.m.
Compression pressure @ 1000 r.p.m.	38 bar (550 p.s.i.)
Injection Timing	The injection timing was arbitrarily set to 20 deg B.T.D.C.
Injection Pump	D.P.A. 3233F161
Injector Nozzle	BDLL150S6443
Opening Pressure	185 atm

5.2 ENGINE TEST EQUIPMENT AND MEASURING METHODS.

The equipment used for this project comprised a combination of conventional test equipment used by many other research establishments for this type of work and equipment designed by Apace Research Ltd. to enhance the measuring techniques.

Typical equipment and methods for the measurement of engine parameters consist of :

(1) Manual reading and recording of fairly stable test parameters such as :
   a. Dynamometer load
   b. Engine speed
   c. Fuel consumption
   d. Various engine and dynamometer temperatures

(2) Recording of cylinder pressures and needle lift by means of an oscilloscope and Polaroid photography. In a number of more advanced engine test facilities ignition delay is measured by means of an ignition delay meter, although this requires a degree of skill on the part of the engine tester.

It should be noted however that more advanced systems are being installed utilising such items as digital storage oscilloscopes, F.F.T. analysers and computer aquisition systems.

The investigation of the effects of different fuels having widely differing ignition characteristics is hampered by the existing manual methods leading to considerable inaccuracies and slow analysis and interpretation.

The equipment and methods used by Apace Research Ltd. for the aquisition of all engine parameters are completely computer based and are believed to offer a degree of accuracy of results not possible with conventional or indeed other methods under development.

The following is a brief description of the equipment and methods used :

(1) HEENAN and FROUDE Type G Hydraulic Dynamometer modified for electrical readout of applied load. The dynamometer is still however manually operated.

(2) Fuel consumption measurement is mass based and comprises a Mettler PE3600 electronic balance equipped with a 2400 baud serial interface. Fuel flow to the weighed fuel container is controlled by a solenoid valve under instruction from the computer. An electric pump delivers the fuel to the engine.

(3) A Kistler Type 6123 Piezo-electric pressure transducer coupled with Type 5041 charge amplifier is used to convert the cylinder pressure into an appropriate electrical signal. Great care had been taken with the installation of this transducer in the cylinder head, mounted vertically with the diaphragm flush with the cylinder head face and well within the piston bowl periphery. It is mounted within a separate tube and a degree of installation compliance has been built in. This is to reduce cylinder head transmitted vibration to the pressure transducer.

(4) The Injector needle lift is measured by means of a C.A.V. Type 1368 FM system consisting of :

a. Inductive measuring coil which detects the movement of the aluminium extension attached to the injector push rod.

b. Oscillator

c. Demodulator/amplifier/filter.

The measuring system produces a voltage proportional to the needle lift.

(5) Heated air is supplied to the engine from an airbox fitted with a thermostatically controlled heater and recirculating fan. The airbox has a volume of approximately 2 cubic metres and air is drawn out of it at a rate dependant on engine demand.

(6) Thermocouples are used to measure temperatures of:

a. Engine cooling water inlet
b. Engine cooling water outlet
c. Sump oil
d. Fuel oil inlet
e. Air inlet 150mm prior to the inlet manifold
f. Air box
g. Exhaust gas approximately .5m downstream of the manifold.
h. Cooling tower water in
i. Cooling tower water out.

(7) The data aquisition and instrument system is under the control of a Hewlett-Packard 86B computer complete with disc drives, HP-IB, RS232 and GP-IO interfaces. Additionally the memory has been expanded to 256k and I/O and Advanced Programming enhancement ROMs have been installed. Although it was not considered an ideal machine for the application it proved adequate in the majority of respects. It's main drawback is the slow Basic operating system. With the time limitations imposed on us by the delays to complete the project it was not considered worthwhile to re-write the programme in machine language.

(8) Equipment described above is conventional in nature, however in order to make the best use of it, it was necessary to design and build a special interface. The interface is based on the S100 bus and briefly consists of :

a. 16 bit address bus
b. 16 bit data bus
c. 4 1/2 digit A-D converter is used for the measurement of all slow changing signals such as thermocouples with a maximum conversion speed of 330mS. A demultiplexer allows differential signals to be steered to the converter via a differential instrumentation amplifier. The BCD coded output of the converter is hardware translated to binary code.

d. A 12 bit A-D converter is employed to convert the voltage produced by the Cylinder pressure charge amplifier to offset binary code. This is then placed into a memory location determined by crankshaft position and specified measurement parameters. A sample-hold amplifier at the input of the A-D converter ensures accuracy of the signal. The conversion rate is in the region of 25 micro-seconds.

e. An 8 bit A-D converter is used to convert the signals from the Needle lift amplifier to unipolar binary code and this is also stored in a specified memory location. Again a sample -hold amplifier is placed at the input to the A-D converter to ensure data integrity. As the output is unipolar, an offset voltage is applied at the input so that only positive voltage is seen. The conversion rate is approximately 4 micro-seconds.
It should be noted that a second 8 bit A-D converter together with sample hold and high gain instrumentation amplifier is installed for use with a fuel line pressure transducer.

f. Five pre-settable down counters. Each counter has associated with it a data latch which can be directly addressed and loaded with data by the computer. The function of the five counters are :

i. Number of measurement samples to be taken
ii. Measurement delay expressed as number of grads after bottom dead centre.
iii. Actual number of consecutive grads when cylinder pressure and needle lift are to be measured and stored in their respective memories.
iv. Cycles between consecutive measurements. It allows the selection of complete engine cycles (two revolutions) when no cylinder or needle lift are recorded.
v. Revolution counter which generates an interrupt signal to the computer that the specified number of revolutions has been completed.

g. An up counter which measures actual engine revolutions and is under computer control. It is used to determine engine speed and fuel consumption.

All the counters are preset to their initial value (data in the latches for the down counters, zero for the up counter) by a trigger signal from the computer.

h. Memories and memory management.
Each high speed A-D converter has it's own 4k of memory, 8 bit wide in the case of the needle lift and 12 bit wide in the case of the cylinder pressure. The memory address is accomplished by means of up-counters which are either addressed by engine crankshaft position sensors during the write cycle or by the computer during the read cycle. Again the counters are preset to their initial value (zero) by the trigger signal from the computer.

i. Electronic switching is used for the RS232 signals so that single serial interface of the computer can be used for reading the fuel measurement system data or writing to a printer. Additional switching is also provided for the GP-IO interface to cater for a plotter drive.

(9) In order to synchronise the aquisition of the high speed data i.e. cylinder pressure and needle lift with the combustion cycle, the crankshaft position must be monitored. This is achieved by means of a disc having 400 slots machined in its periphery, each slot corresponding to one grad. One of the slots is longer and corresponds to No1 crank being at bottom dead centre. Two infra red sensitive photo transistor/ diode sensors coupled with Schmitt triggers sense the slots and output a square edged pulse each time a slot passes the detector. Thus one detector produces 400 pulses per crankshaft revolution while the other produces only one pulse at bottom dead centre per crankshaft revolution. A proximity type switch is installed near the camshaft gear which is fitted with a steel flag indicating whether the compression/expansion part or the exhaust/ induction part of the combustion cycle is in progress.

The combination of the three sensors together with some counters can therefore determine the crankshaft position within a combustion cycle to within one grad. (0.9 deg = 1 grad)

The measurement methods are fairly simple and operate in a number of different modes. These are :

(1) Idle mode.
In this mode the only measurements that are taken are the slow response ones i.e. temperatures, torque and engine speed. A complete measurement cycle takes approximately 10 seconds. This is useful for monitoring engine parameters for stabilisation and setting up for a more complete measurement mode. The computer always starts up in this mode and always reverts to it at the completion of any other mode. Exit from this mode to any other mode or function is accomplished by use of the special function keys. While in this mode it is also possible to alter all the measurement parameters such as grads delay,number of samples, number of revolutions for the fuel consumption measurement and number of grads to be read.

(2) Beginning of injection mode.
The purpose of this mode is to aquire needle lift data during the latter part of the compression stroke and early part of the expansion stroke and calculate by the use of a suitable algorithm the dynamic starting point of injection. This allows for re-adjustment of the pump timing to obtain the required dynamic commencement of injection.

The programmed default parameters are :

a. One sample only
b. Grads delay set to 150 grads
c. Grads measured set to 100 grads. These can, of course, be altered by entering the required data into the computer. This allows the study of either short term or long term changes in engine parameters by varying the sampling period.

(3) Ignition Delay.

This mode is identical to the Beginning of injection mode in all aspects but also includes the cylinder pressure data, number of revolutions and time taken to complete that number of revolutions. Once the data has been collected and commencement of injection calculated then another algorithm is used to determine the start of combustion from the cylinder pressure data. It is then a simple matter to establish the ignition delay from the time and number of revolutions both in terms of time and crank angle.

The additional default parameter is the number of revolutions and is set to 100. Again if higher accuracy or greater number of samples are required then this parameter can be easily re-specified.

When either the beginning of injection or this mode is specified an internal computer flag is set which enables, at the completion of the measuring cycle, for needle lift and cylinder pressure data to be graphically displayed on the computer monitor. Additionally the commencement of injection and combustion are marked together with grad marks and top dead centre.

(4) Full run.

This mode is selected when the engine has reached correct specified operating conditions such as

a. Water temperature
b. Oil temperature
c. Air inlet temperature
d. e.t.c

and the engine speed and load have been set and stabilised.

The following sequence takes place when this mode is entered :

i. A quick check is made of the engine speed over 100 revolutions and stored.

ii. A calculation is made how many readings of engine load and all temperatures (i.e. how many idle loop equivalents) can be made within 1000 revolutions at the speed obtained in (i.). This determines how many readings of these parameters will be taken during the full run. This figure is however deliberately limited to five and if neccessary the computer will enter into a wait state to achieve equally spaced readings.

iii. The fuel feed to the fuel measurement system is switched off and a wait period of five seconds initiated.

iv. The counter latches are set up with test conditions, the default ones being:
a. Samples = 5
b. Delay ,grads = 10
c. Number of grads measured = 780
d. Number of cycles between samples = 89
e. Number of revolutions = 1000
Note that the number of cycles between samples (89) + 1 sample = 90 so that a sample is taken every 90 engine cycles or 180 engine revolutions.

v. The memory address counters are set to zero.

vi. The RS232 port connected to the balance is selected and the buffer registers in the serial interface cleared. Two consecutive readings from the balance are read by the computer and the first one rejected, the timer is started and all counters loaded with data from their respective latches and enabled by common trigger signal. The interrupt from the down counter is also enabled.
At this point the Apace interface commences to collect data from the cylinder pressure, needle lift and (when available) fuel line pressure at every specified grad and storing the data in the relevant memory locations.

vii. While the interface is collecting and storing the rapidly changing data the computer performs basically a number of idle loops as established in para. ii.

viii. After the specified number of revolutions have been completed an interrupt is generated by the interface and the computer responds to this by checking that the balance RS232 port is still connected, clearing the serial interface buffer registers of accumulated data,again accepting two readings from the balance and rejecting the first one. At this point it stops the revolutions up counter and reads the elapsed time from the start of the measurement cycle.

ix. The computer now restarts the fuel flow to the fuel consumption measuring system and commences the data transfer from the Apace interface memory into it's own memory. On completion of the data transfer internal flags are set to signify that the data is now ready to be stored on disc, displayed graphically on the monitor, selected data output to a printer or to a plotter .
The last two features were not utilised during this series of tests as vast quantities of data were collected and it was preferable to process the data in a less hostile environment.

x. The computer now re-initialises all setup parameters back to the idle loop conditions and restarts that loop.

The statistics of this type of data aquisition are quite surprising. Typically a single full run mode would produce in 1000 engine revolutions the following amount of information :

* 3900 data points for needle lift
* 3900 data points for cylinder pressure
* 3900 data points for fuel line pressure(when available)
* 5 applied load readings
* 50 temperature readings (5 of each measured temperature)
* 2 fuel mass readings (one at the commencement, the other at the end of the test run)
* Elapsed time between the two fuel mass measurements
* Number of engine revolutions occuring during the elapsed time.
* Barometric pressure

Additional information that must be recorded includes such items as Test ID, Fuel ID, Fuel density, Fuel calorific value, Date, Record ID, Number of samples, Number of cycles between measurements, Grads delay, Number of grads measured, Engine specification, Dyno parameters and any comments.

In spite of virtually all information being stored in condensed form this still amounts to 16500 bytes per full run mode. The method selected for fuel evaluation requires 16 runs (3 different loads at 5 speeds and one idle condition) and thus 264,000 bytes of information have to be stored per single fuel.