THE CITY UNIVERSITY
THERMO-FLUIDS ENGINEERING RESEARCH CENTRE

Confidential Research Report TFERC 01/1286
Submitted to Robert Fraser & Partners Ltd.
December 1986

PRELIMINARY ASSESSMENT OF AN ADDITIVE MIX TO DEHYDRATE DIESEL OILS USED IN COMPRESSION-IGNITION ENGINES

by

Dr. A.R.D.Thorley

CONTENTS

INTRODUCTION

At the request of Robert Fraser & Partners Ltd., the Research Centre has undertaken an assessment of information provided by Mr.P.Street of the Enersolve Chemical Company Ltd., with regard to a chemical compound called the Enersolve Diesel Fuel Additive (EDFA).

In this preliminary investigation the Research Centre was asked to accomplish the following:-

1. Confirmation that tests carried out in Texas and Louisiana, of which we were already in possession of reports, are the conventional preliminary tests that would be used to achieve the results expressed in these reports.

2. The proposal to introduce a diesel dehydrator would be feasible within the present level of technology and that we would carry out basic mixing and engine tests to confirm this, utilising the Enersolve compound, and

3. After full disclosure of the formulation, provide an initial opinion as to the likely acceptability of the Enersolve compound, to both the engine manufacturing industry and the consumer, and comment on the likely beneficial effects of the Enersolve compound on the engine itself, together with any potential adverse effects.

SUMMARY AND CONCLUSIONS

1. Test procedures undertaken in the reports from Louisiana and Texas A and M Universities are typical of preliminary investigations that would be used to assess the comparative performance of normal and modified fuels.

2. The present level of technology is conducive to the development of an additive to dehydrate diesel type fuels. The major outstanding problems are associated with the stability of water contaminated fuels when attempts are made to emulsify them.

3. Basic mixing tests at The City University with Enersolve compound, a surfactant and a binder have shown that an Enersolve Diesel Fuel Additive (EDFA) can be made which will convert a non—homogeneous water contaminated diesel fuel into a clear homogeneous solution.

4. The resulting solution has remained stable for some two weeks (i.e. from mixing until the time of writing).

5. Comparative tests on a Ricardo E6 Fuel Research engine have produced encouraging results, supporting a case for continuing the development of the EDFA.

6. The concept of fuel dehydration should be acceptable to engine manufacturers and users — both for dehydration per se, but also from environmental considerations such as less toxic exhaust emissions.

7. Ingestion, inhalation and prolonged skin contact with the concentrated raw ingredients can be hazardous. If the normal rules of proper industrial hygiene are followed there should be no significant risks to personnel engaged in research and manufacture.

8. There should be no difficulty, however, in providing an end product sufficiently diluted that health hazards are no more severe than those associated with modern substances (adhesives, super glues, etc.) on sale to the general public.

9. A research programme has been formulated to address issues relevant to optimising the mix of ingredients for best performance, materials compatibility for the complete fuel system, engine components and exhaust system and effects on exhaust gas emissions.

DIESEL-WATER EMULSIFIERS AND DEHYDRATORS

Diesel—water emulsions have been investigated for a number of years with interest being directed primarily at their use as fuel—extenders and in some circumstances for improved power output. Developments have not been very successful due largely to problems of the stability with time of the emulsions and corrosion of fuel systems and engine components.

Stability problems have been found to be particularly acute with the higher fraction distillate hydrocarbon fuels (gasoline, kerosene, and normal diesel fuels) with separation tending to occur in seconds or minutes. Insofar as successes have been achieved they have been effected as a result of water injection in fuel lines just upstream of the fuel pumps. It was generally found necessary for fuel lines to be purged with **just** diesel fuel prior to shutting down the engine to avoid pockets of water forming and creating subsequent starting problems.

Corrosion problems, including biochemically aggravated corrosion, and gumming up of moving parts in injectors and pumps have been encountered. These have been countered to some extent with the development of biocides.

The fundamental outstanding problem that must be overcome is that of stability of the homogeneous diesel:water mixes.

It is this feature that it is claimed has been resolved by the Enersolve Diesel Fuel Additive for fuel dehydration, and which is the reason for the investigations described in this report.

ENERSOLVE DIESEL FUEL ADDITIVE

The EDFA, as provided for the investigation described in this report, comprised a surfactant, a ‘compound’ and a ‘binder’.

The surfactant originally provided came from the United States and was some 12 months old. An alternative having apparently the same properties was obtained by way of a free sample in the U.K.

BASIC MIXING TESTS

Bench top mixing tests have been carried out. Initially these were to establish the relative properties of the surfactant, compound and binder to form the additive.

It was then established that by taking a vessel containing 100 parts of diesel fuel, to which was added 10 parts of tap water, by volume:-

a) a clear translucent solution could be formed by introducing a suitable quantity of EDFA.

b) samples of these mixtures remained clear and apparently stable after some two weeks, and

c) it also appears possible to retain the mixture in the form of a micro—emulsion (i.e. not as a homogeneous solution) for at least several days by varying the proportions of the ingredients of EDFA.

PREVIOUS ENGINE TESTS

The test procedures described in the reports from Louisiana and Texas, and handed over by Mr.Street, are typical of the preliminary investigations that would be undertaken to assess the comparative performance of fuels and additives. Similar tests have now been conducted at The City University.

CITY UNIVERSITY (TFERC) ENGINE TESTS

All tests have been conducted on a Ricardo E6 single cylinder four stroke compression-ignition engine in the Applied Thermodynamics Laboratory.

The compression ratio was set at approximately 22 : 1.

Injection timing was set at 35 before T.D.C., though two spot checks were made in one test at 2500 rev/mm of the effects of varying this.

The speed range for normal testing is from 800 - 3000 rev/min, and the engine is connected to an electrical dynamometer.

Measurements of cylinder pressure and of several temperatures can also be made.

Two sets of comparative tests have been conducted to investigate the relative merits of normal diesel fuel and dehydrated fuel.

The first set of tests was at a constant engine speed of 1500 rev/mm to obtain engine torque as a function of pump rack (i.e. throttle) setting.

The second set of tests enabled performance curves of net load or torque at nearly full throttle to be generated as a function of engine speed in the range 800 — 3000 rev/min.

RESULTS

Constant Speed Tests - at 1500 rev/min

Figure 1 illustrates graphically the comparative torque output for normal diesel fuel and dehydrated fuel in the form of a clear solution.

It is noted that except in the region of full throttle opening, for a given throttle setting (and hence fuel consumption rate), the torque output from a normal diesel fuel is higher than when EDFA is added to dehydrate a diesel:water mix. Expressed another way - to obtain a given torque, and hence power output, with a dehydrated fuel it is necessary on this test engine, at 1500 rev/min, at low powers, to increase the throttle opening.

Torque-Speed Tests at near Full Throttle

By adjusting the load on the torque dynamometer whilst maintaining a constant throttle rack setting, equivalent to about 5.2 on Figure 1, data for Figure 2, which is a typical performance curve were obtained.

At engine speeds below about 1600 rev/mm the dehydrated fuel provides a greater power output than normal diesel. From 1600 rev/min up to around 2100 rev/min the position is reversed with normal diesel apparently being slightly better, and above this speed normal diesel fuel is considerably better.

However, these tests were conducted at a constant injection timing. Spot tests at 2500 rev/min with both normal and dehydrated fuel indicated that performance would be improved by advancing the injection timing and also that a greater improvement occurred with the dehydrated fuel. If injection timing can be optimised over the speed range the benefits of improved performance at this throttle setting should be extended to a speed rather higher than 1600 rev/min.

The principal positive conclusion from these tests is that, on this Ricardo E6 engine, at nearly full throttle opening, and over a speed range of, say, 800 - 2000 rev/min, a dehydrated fuel which had been contaminated with 10% tap water yields essentially the same, if not a slightly improved, power output as a normal 100% diesel fuel oil.

Running Temperatures

Exhaust temperatures, and hence cylinder temperatures, were lower with the dehydrated fuel — the results from the constant speed tests being illustrated in Figure 3.

At this stage these data are included only to demonstrate that EDFA does not increase operating temperatures and will not introduce problems due to the overheating of engine components.

Exhaust Emissions

No quantitative tests have yet been conducted though it is claimed that emissions are improved.

An approximate assessment of soot emissions was made by comparing the extent to which a sheet of white paper was blackened over a timed interval. The staining was noticeably less with the dehydrated fuel.

PRODUCT SAFETY AND ENVIRONMENTAL ASPECTS

It is anticipated that although some care in handling and using EDFA will need to be specified it will be no more hazardous than many of the modern chemical compounds, (e.g. binary adhesives, super glues, special purpose paints, etc.) encountered in the domestic and industrial scene. Greater care and safety awareness will, however, be required during the manufacture of EDFA and its handling in concentrated form.

Surfactant

Surfactants commonly used in attempts at creating oil—water emulsions and mixtures are of a form that are frequently used in industry. The one used in the tests reported here is from a family that has been extensively studied in the U.S. Toxicity tests have been primarily carried out with animals, supplemented to some extent by human patch tests.

Ingestion of surfactants is unlikely, even accidentally, and surveys of the results of such incidents (Human Toxicol. (1982), 1, 403 -409) indicate that the consequences are usually very minor.

Severe eye irritation due to splashing can be a problem but the effects have usually been resolved quickly with no indication of permanent damage.

Prolonged skin contact with the undiluted surfactants should be avoided as they have been known to be moderately to severely irritating.

Safety precautions recommended, particularly when dealing with the undiluted substances, are:

i) avoid contact with skin, eyes and clothing

ii) isolate from heat, naked flames and sparks

iii) keep eyewash bottles filled with clean water and readily available.

Binder

As the ‘binder’ is a volatile fluid with a flash point of around 60°C it should be used in a well ventilated region. On exposure to light and air it is liable to form peroxides which can be hazardous.

In the event of inhalation, eye splashes, skin contact or ingestion of the concentrated fluid, manufacturers recommend that medical attention is obtained and comment that repeated exposure can result in liver and kidney damage.

Perhaps fortunately, only small quantities are required for EDFA.

Enersolve Compound

No details of the ingredients are yet available.

Safety Precautions

1) For Testing and Manufacture

This should only be undertaken in well ventilated areas by personnel familiar with the hazards associated with the constituents.

Protective equipment by way of goggles, glasses or face shields, suitable rubber or plastic gloves, apron and plastic boots should be worn if there is a risk of substantial body contact.

ii) For the End Product

The end product that is intended for use by the public should be sufficiently diluted as to render it no more harmful than other modern chemical compounds on sale to the general public.

Cartons and containers should carry appropriate hazard warnings regarding storage and use.

POTENTIAL BENEFITS AND APPLICATIONS

All potential applications must be assessed ultimately on the basis of improved performance, expected cost savings, extending the life of natural resources and on environmental considerations. Detailed discussion of these are outside the scope of this preliminary report which is concerned mainly with the technical aspects.

So - called diesel fuel and its close relations are used in:- compression ignition engines

certain types of boilers, and gas turbines.

Insofar as it has been found that a particular diesel engine ran successfully for the duration of the tests reported herein, such engines represent a potential application.

The results do suggest that the larger, slower running, stationary diesel engines represent the most likely candidates for consideration, assuming more exhaustive tests do not yield technical problems and that EDFA is still economically attractive.

Such engines are used in water supply, power generation, railways, heavy earth moving equipment, etc.

Dehydration of certain boiler fuels and gas turbine fuels (aviation, tank power units) also represents significant potential areas for development.

Taking the longer term view consideration should also be given to the development of fuel extenders but also combining the design of both engines and the fluids they use to optimise performance.

It is believed that there is scope to investigate some of these ideas in a computer model of internal combustion engine cycles in which factors such as fuel dilution, engine speed, ignition/injection timing, compression ratios, and cooling rate at different parts of the system, could be introduced. This could be a valuable guide to a long term experimental program, perhaps in conjunction with an engine manufacturer. The Thermo-Fluids Engineering Research Centre has the capability to undertake both these computer and experimental research programmes.

FURTHER WORK

It cannot be emphasised too strongly that the tests and their results presented here refer to work on one engine under a restricted range of conditions. Their purpose was merely to establish whether or not there is a *prima facie* case for a more exhaustive study. It is believed that such a case has been found.

To this end, a Research Proposal has been formulated and is attached as an Appendix. It provides details of the technical aspects that it is believed require continued investigation, together with a time schedule for much of the work.

ENERSOLVE DIESEL FUEL ADDITIVE (EDFA) DEVELOPMENT PROGRAMME

PHASE I - DIESEL DEHYDRATION

START — 6 months — 12 months

Bench Testing

Mixing and stability tests; temperature effects, viscosity, substitute ingredients, fluid properties, etc.

Continue as necessary, checking significance of additive properties and ingredients -assessing alternatives ,etc.

Materials compatibility testing ....— — —>

Set up 2 (or more) *pump—injector* recirculation rigs for Fuel and Fuel+EDFA for long term wear and reliability tests.
Monitor wear rates, corrosion (if any), fuel degradation, etc..

Preliminary Engine Testing

Set up a typical 100—200 hp multi—cylinder modern diesel engine on a basic test bed to obtain general engine response data for initial product development and demonstration and to assess the scope for more extensive exploitation and development of the Enersolve compound, if required.
Define nature and scale of any necessary additional development and testing, and the facilities required.

DIESEL FUEL DEHYDRATION AND ADDITIVE PROJECTS

Purpose: To assess the merits of proposed fuel additives.

Aspects that ultimately need to be addressed include the following:
1) The need to meet National & International Standards (ASTM or IP) concerning:
Emissions visa vis pollution and health, etc.
Cetane rating
Any other additives required e.g. antifreeze

2) Fluid Properties and how they are affected:
Viscosity, Self-ignition Temperature (sit)
Calorific Value
Temperature changes (extremes of heat and cold)
Surface tension/atomisation properties
Aging effects: Time effects per se
Agitation and vibration.
Light, etc.
Contamination - other fluids, corrosion products Tolerances on methods of additive production
Optimisation of the combination of ingredients to produce the complete additive
Availability and efficacy of substitute ingredients Tolerances on additive quantities for diesel fuels of different countries, manufacturers and specifications

3) Engine Performance per se plus any consequences of 2) above:
Comparisons with normal fuels
Responses to varying loads/accelerations
Exhaust gas analysis
Contamination of lubricants
Corrosion - long term effects on performance and life
Changes to operating conditions for peak performance e.g.

Running Temperature
Fuel injection timing and ignition delay periods
Mixture strengths Compression ratio

Effects on components e.g. injectors, exhaust systems, valves, fuel systems (from fuel tank to engine)

4) Diesel Engine Types to be considered:.
a) Stationary plant e.g. driving pumps, generator sets, etc. at constant or near constant load and speed
b) Vehicle power units, usually smaller but requiring variable speed and power, and quick responses to load changes
c) as a subset of (a) and (b) engine types need to include both naturally aspirated and turbo-charged, direct and indirect injection.

5) Costs of ingredients, manufacture and of any necessary modifications to engines and ancillary equipment.

Approval by engine manufacturers for warranty purposes. Implications re. Customs and Excise duties on fuel.

ARDT. .
12th December 1986

ENERSOLVE FUEL ADDITIVE (EDFA) DEVELOPMENT PROGRAMME
PHASE I Ia - FUTURE DEVELOPMENTS

START — — — — — — — — 6 months — — — — — — — — — — 12 months — — — — — — — — —

Future Developments

i) Dehydration of Petrol:
Test programme essentially similar to that for diesel, as a feasibility study.

ii) Dehydration of Kerosene/Gas Turbine Fuel
a) Bench testing and materials testing similar to that for diesel

b) Define and execute tests on a representative gas turbine type combustion chamber, monitoring performance data such as exhaust temperatures and constituents, spray patterns and atomisation characteristics.

iii) Dehydration of Boiler Fuel Oils
(i.e. higher fraction gas oils, etc.)

Feasibility study to define classes of oils
to be considered

Execute tests for stability, fluid properties,
materials compatibility, etc.

Execute spray and burner tests, including
boiler tests, etc., as appropriate.