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14875

UNIDO/IO
ENGLISH
JUNE 1985

India.

APPLICATION OF ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES, IIP, DEHRA DUN.

DP/IND/82/001
INDIA

FINAL REPORT *

Prepared for the Government of India,
by the United Nations Industrial Development Organization,
acting as Executing Agency for the United Nations Development Programme

Based on the work of Mr. Hans C. Wolff
Expert on Lubrication and Wear
Characteristics of I.C. Engines
Under the post 11-03

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Part A: EXECUTIVE SUMMARY

1. Preface

1.1 Large scale research and development on lubrication and wear in methanol fueled engines is going on in several parts of the World. In America, Germany and New Zealand fleets of buses and passenger cars are running in day to day operation successfully. The problems of lubrication and wear are solved for buses using methanol engines derived from diesel engines. 4 stroke passenger car methanol engines are sometimes still showing higher wear under cold driving conditions.

1.2 The task of the project is to recommend to the Indian engine manufacturers a lube oil suitable for methanol engines. This engine oil should be based on components produced or produceable in India. Its practical performance should be proved in an Indian built engine.

1.3 To achieve this task in the short time span given to the project the expert brought along a reference oil "Formula 222A" which had shown high performance in practical field trials by Bank of America in California. As the next step the Indian built 4-stroke Diesel Kirloskar AV1-Engine, which has been used at IIP with neat methanol (ignition by glowplug) and methanol addition upto 25 % by fumigation, had to be set up as a lube oil test facility. The same engine has been used at IIP for wear measurement by radio tracer technique. This technique should be included in the lube oil evaluation. It could reduce test time and would allow testing of several oils side by side.

1.4 To obtain an Indian produced or produceable methanol engine oil the expert has contacted Lubrizol India Ltd (LIL) in Bombay, which is the only additive producing Company in India. It operates in close cooperation with THE LUBRIZOL CORPORATION, USA. There, an additive package for methanol engine oil has been developed and successfully engine tested. The expert has convinced the management of LUBRIZOL that it is possible and advantageous for all partners if this additive package, mixed into an Indian base oil and made from components, which could later on be produced at LIL, Bombay, would be incorporated in the engine test series at IIP.

1.5 By comparing engine wear results when using the different oils (Formula 222A from BoA, Formula OS 70336 from Lubrizol and an normal Indian lube oil), IIP will be able to recommend to the Indian engine manufacturers a suitable oil for their methanol engine development work. The engine manufacturers in turn can find out if they are facing difficulties during the development, whether these are oil related or not.

1.6 The lubrication of methanol fueled 2-stroke engines is facing a principal problem. Mineral oil base stocks are not mixable with neat methanol. For methanol 2-stroke engines running on oil/fuel mixtures synthetic base oils like polyglycols are needed. LUBRIZOL has supplied 5 gallons of such a synthetic 2-stroke oil mixable with methanol (OS 59770).

1.7 Some 2-stroke engines are using separate lubricating systems and not oil/fuel mixtures. Even in this case the use of mineral oil based lubricants is not possible because heavy deposits will be formed if mineral oil is coming into areas flushed with methanol.

1.8 The situation might change if methanol/gasoline mixtures are used in the range of 50/50. Some screening tests in this area should be started.

A decision on the type of "Project Test Fuel" is needed to set a frame for this test work.

1.9 For <u>all</u> lubrication evaluation tests a constant fuel quality is needed to keep the variables as low as possible and to improve the reproduceability.

The water content in methanol used as test fuel by IIP was between 1800 and 55450 ppm whilst the international standard is asking for <u>max</u> 1000 ppm.

2. Achievements

General:

2.1 In 3 lectures (Full text see Part C) the results of field tests in Germany (FRG), basic facts on lubrication of methanol engines and laboratory tests have been presented to the staff of the engine laboratory. Interesting discussions were the result.

A proposal how the introduction of methanol fuel in India could be pursued did emerge. (See Part B, page 22).

2.2 Two copies of the book "Lubricants and Related Products" (1984) by Prof. D. Klamann were handed to IIP as a gift.

2.3 The expert has established for 2 engineers from IIP engine laboratory personal contacts in Germany (FRG) to visit engine laboratories of motor- and oil-industry as well as the most developed air pollution laboratory of TUV Rheinland, Cologne. Discussions with Technical High School, Aachen, (Prof. F.Pischinger) are also arranged.

2.4 The project coordinator, Mr. S. Singhal has after detailed discussions with the UNIDO Experts, Prof. A.S. Khatchian, Dr. S. Radzimirski and H.C.Wolff changed part of the organisation in the engine laboratory to improve the efficiency. Measures to obtain more accurate results are being taken.

2.5 The safety measures in handling methanol in the engine laboratory have been discussed. Improvements and a continuous training programme for the workers has been set up.

4-Stroke Engines

2.6 The Kirloskar AV1 single cylinder engine was optimized (Mr. Dinesh Kumar) when running on neat methanol. The expert organised the supply of special glowplugs with built-in thermocouples from Germany (FRG). It was possible to reduce the glowplug energy consumption from 180 W at rated engine output to ~ 100 W. The output of the engine with methanol could be increased to 4.2 KW at 1600 RPM as compared to diesel fuel 3.75 KW at 1500 RPM. The exhaust smoke (Hartridge Units) with methanol was "8" as compared to "80" with diesel fuel.

Further engine optimization is in progress.-

(Dinesh Kumar)

2.7 The Kirloskar AV1 engine was then set up as a luboil test facility (Dr. P.C. Nautiyal, Ashish Kumar Gondal). A 50 hrs test cycle has been developed as against the 120 hrs test used before.

Further improvement of the reproduceability is recommended.

2.8 On request of the expert THE LUBRIZOL CORPORATION, USA, has sent by airfreight to IIP 113 ltr. of a methanol engine oil, which can later on be produced at LIL, Bombay, (OS 70336).

The expert has brought with him 50 ltrs of a methanol engine oil, which has been used successfully in field tests over more than 1 million miles in California by Bank of America. This oil "Formula 222A" can therefore be used as a "yardstick" for engine oil development at IIP.

2.9 Since 07/05/85 the Kirloskar AV1 Engine in the Radiotracer Lab has completed 10 luboil tests of 50 hrs duration each in 30 days only. This great number of tests in very short time indicates the endeavour of the group working on this project and the reliability of the Kirloskar AV1 Engine even running on methanol and under arduous conditions.

The oils were rated by the engine in the expected order. The 2 methanol engine oils (Formula 222A and Lubrizol OS 70 336) showed the same low wear figures with methanol fuel as with diesel fuel, whilst the top ring wear with normal Type 3 luboil was about twofold with methanol fuel.

It became obvious, however, that the absolute wear figures can be compared only if the different fuels or oils are run in the same assembly (piston and liner) and if this assembly has shown normal wear during running-in with diesel fuel.

(Details see Part C Appendix 10, Report by Dr. P.C. Nautiyal, A.K. Gondal).

2.10 Arrangements to use radioactive piston rings in the Kirloskar AV1 engine are in progress. A programme to study the influence of the cooling water temperature on the wear of the cylinder liner and the piston rings has been established (Dr. P.C. Nautiyal, A.K. Gondal).

<u>2-Stroke-Engines</u>

2.11 In support of the 2-stroke engine development supervised by the UNIDO expert Dr. S. Radzimirski THE LUBRIZOL CORPORATION, USA, has sent 5 gallons of a synthetic 2-stroke oil, fully soluble in methanol (OS 59 770) to IIP. The results in the seizure and tightening test were good in respect of lubrication. The oil /fuel (methanol) ratio could be reduced to 1.5 %. But the carburettor became somewhat dirty in a short period and idling could have been adversely affected. (Details see Part C, Report Mr. Mukesh Gupta, page 190).

2.12 To rectify this shortcoming the expert has added his "Additive W" for which a patent application will be put forward. This measure has kept the carburettor

absolutely clean and improved the lubricity further. A further reduction of the oil content will be possible.
Longer duration tests are in progress (Mr.Mukesh Gupta).

Fuel additives.

2.13 The expert brought along with him a fuel additive, "Metacor 704" which has been used successfully by Bank of America in field trials in California. This additive showed much better results in a corrosion test set up by Mr. A. Jayaraman, IIP, (Details see Part C page..181..) as compared with two other corrosion inhibitors commercially available from U.S.A.

2.14 The expert has arranged for two further fuel additives especially developed for methanol fuels by Du Pont, USA, to be sent for test at IIP. These additives (Du Pont DGOI-100 and Du Pont DCI-11) have obtained a waiver from EPA, Washington USA, only in January, 1985. Their use is required in USA when running on alcohol-blends containing upto 5 % methanol.
The additives have arrived in the 1st week of June at IIP.

(Details see Part C, Appendix 5).

3. Recommendations

3.1 First of all a reliable 24 hours power supply (constant voltage and frequency) has to be established at least for the analytical and the engine test sections. At the moment none of the costly, sophisticated analytical equipment, supplied mainly by UN sources, can work effectively due to frequent power cuts.

This situation is responsible for the fact that,

a) the necessary analytical results are not available in time;
b) no time table can be kept;
c) the working moral at the engineers and technicians level is adversely affected because only little success of their work can be shown. *See page 217.*

3.2 Research and development in the field of lubrication and wear is basically an on-going task for the Indian Institute of Petroleum. This field lies between the sciences of physics, chemistry, engineering and metallurgy. To achieve results it is necessary to coordinate informations from all these fields under the aspect of lubrication and wear. Only by real team-work successful developments can be expected. Even so the experts in each field will work in different divisions of the institute a frequent personal contact to discuss mutual questions should be organised. As a management tool the credit for a success should not be given to a person but to the group.

3.3 A lot of the simple equipment like brakes, temperature gauges and exhaust gas measuring instruments need general overhaul. The accuracy of this equipment has to be improved to obtain more reproduceable and repeatable results.

3.4 The 50 hrs-low temperature- wear test in the Kirloskar AV1 engine as now established should be improved in its repeatability by contrelling all parameters like fuel consumption, engine load and speed, cooling water temperature and exhaust composition more closely.

3.5 The actions recommended under 3.4 are of particular importance for tests with radioactive rings, because these should be used to test different oils side by side in rather short tests.

For the radioactive tests it is recommended to install a pressure pick up in the cylinder head of the Kirloskar AV1 engine because by this constant control of the combustion process it will be possible to obtain more repeatable results. Changes in the combustion process can influence wear results strongly.

3.6 Using radioactive rings it might be possible to determine

a) the cooling water minimum temperature to prevent erratic wear in engines;

b) the wear pattern over running time, which is expected to show a sharp increase at the moment when the additive activity has come down to a certain low level.

Both these results would be of great interest to engine manufacturers.

3.7 A system to change the oil in the Kirloskar AV1 engine when running might be developed. Such systems are used in other laboratories in different engines. Such a system could help to compare different oils under absolutely the same conditions.

3.8 All tests run in the Kirloskar AV1 engine with neat methanol (99 % methanol + 1 % castor oil for injection equipment lubrication) should be repeated with M 85 (85 % methanol + 15 % gasoline) since this might become the "Methanol-Fuel of the Future" due to safety requirements.

3.9 Since a suitable methanol engine oil for 4-stroke engines will be available from LUBRIZOL INDIA LIMITED (LIL), Bombay, (OS 70 336) fleet tests in city buses should now be arranged. However, it is important, that this can be done with full support of the engine manufacturer only. In Germany (FRG) the federal government has provided financial incentives to the motor manufacturers for the development of methanol engines, since the full commercialization was still several years ahead. This action has helped tremendously to speed up the development. Now, after the successful field trials, the further development is pushed by the competition between the engine producer, since first orders for methanol fueled city buses have been received.

3.10 The development of 2-stroke methanol engines should be reviewed carefully. These engines would replace gasoline, which will be available in India always plentiful as long as diesel fuel is needed.

Before continuing the 2-stroke methanol development a decision on the fuel composition has to be taken since this will influence the possibilities of the lubrication in its basic approach.

If mixtures of gasoline/methanol containing upto 50 % methanol are used, then some improved mineral oil based lubricants might be applied. If the mixtures contain more than 50 % methanol then synthetic base stocks have to be used. Polyglycols are the most common material for this purpose. Castor oil is being used for short term trials upto now, but it would have to be further developed for long term use. This has been tried for racing engines since many years but with limited success only.

3.11 Lubrication and wear studies have to take into account the combustion and the fuel composition since these factors influence the requirement of the engine.

Clean and complete combustion is a pre-requisit for luboil testing. Therefore, the combustion parameters have to be controlled carefully during luboil engine tests.

Changes in the fuel composition and impurities in the fuel can influence the results of luboil tests. Therefore, a realistic test fuel has to be decided on. The expert is suggesting to follow the proposals made in Europe and USA. For safety reasons- to obtain a visible flame if the methanol fuel is burning accidentally - a mixture of 85 % A grade methanol + 15 % leadfree gasoline should be used. (Details see Part B).

3.12 To minimize the influence of the test fuel quality a system of quality control for the components used has to be installed. The storage and handling facilities have to be improved. Frequent quality control of the test fuel directly before the luboil test engine should be pursued since contaminations like the pick up of aluminium during storage and handling can influence the test results greatly.

It is recommended that one person who reports directly to the head of the engines laboratory should be responsible for the quality control of the test fuel.

3.13 The 1 % castor oil used in the methanol fuel upto now for lubrication of the injection equipment should be reduced or even better replaced, because this castor oil is giving a lot of deposits on the piston, e.g. in the combustion room of the Kirloskar AV1. This development, however, can only start after the final test fuel (see proposal 3.11) has been decided on.

4. Acknowledgement

4.1 The expert would like to thank all those persons, who have assisted him and the UNIDO-Project by supplying special oils and engine hardware. These oils and parts were not commercially available and therefore, invaluable. They were decissive for the success of our project. The respective persons are:

Mr. M.R. Litton, Vice President World Trade Bank of America, San Francisco, USA.

Mr. Charles, C. Colyer, Chief Technical Adviser, THE LUBRIZOL CORPORATION, USA.

Dipl. Ing. A. Neitz, Manager Engine Research M.A.N. Nurnberg, FRG.

Dipl. Ing. F. Chmela, Engine Research M.A.N. Nurnberg, FRG.

Dipl. Ing. G. Finsterwalder, Engine Research KHD, Development Dept. Köln-Porz, FRG.

4.2 Based on his vast experience Dr. M. Kamal Hussein, SIDFA - UNIDO - New Delhi has helped the expert a lot with his personal advice.

The cooperation with the UNIDO-Experts Prof. A.S. Khatchian and Dr. S. Radzimirski was extremely fruitful.

4.3 Last but not least the expert would like to thank the Project Coordinator Mr. S. Singhal, who worked many hours overtime to assist in difficult situations and who was always prepared to listen to problems. He and his staff, including the Secretariat, are working with such an endeavour on the project that it has been a great pleasure to be part of this team.

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Part B: WORK DONE by the Expert based on the DETAILED PROGRAMME of work as submitted on 8/1/85

1. Report on METHANOL FIELD TESTS IN GERMANY to the staff of the engine laboratory (lectures)

This subject was split into 3 lectures:

03/01/85 "German field tests with methanol engines".
04/02/85 "Lubrication of M 100-Engines".
19/02/85 "Wear in methanol engines".

The basic idea of this series of lectures was to build up an understanding of the suggestions put forward by the expert for lube oil testing in methanol engines. The lectures created useful discussions, which are summarized below.

On request of the project coordinator the full manuscript of the lectures including copies of the figures and tables are submitted as Part C. (appendices to the final report).

1.1.I. Results of discussions on the report of GERMAN FIELD TESTS WITH METHANOL ENGINES

(Lecture text is given as Part C of the final report

1. In Germany at the time being M3 (3 % methanol in leaded gasoline max 0.15 gr.Pb/l) is used. This was agreed between the motor industry, responsible for material problems and engine performance, and the mineral oil industry, responsible for supplying within the DIN standard of fuel quality.- After cleaning and drying of the whole supply system no principal complaints from customers are obtained. The use of at least 1 % of methanol should not be interrupted in order to avoid the build up of water-bottoms and consequent rusting in the system.
2. The possibility of using M 15 was demonstrated in large scale field trials lasting more than 3 years.

All technical problems could be solved. It became clear, however, that M 15 - vehicles would have to use M 15 always in order to stay within the air pollution limits. Therefore, M 15 would become a "new grade" at the filling stations. The total investment for supply equipment and new M 15 cars would be high. However, in the long run M 15 would not be a solution of the mineral oil problems because more methanol would be available after the year 2000 then could be absorbed by M 15. (See fig. 25 and 26 in Appendix 1). Therefore, now M 100 is in the forefront of research and development.

3. M 100 has proved to be a full substitute for diesel fuel in city buses. Regular services with Daimler Benz and MAN-Busses are run in Berlin (FRG) and Auckland (NZ). KHD-Methanol Engines are used successfully in day-to-day work of street cleaning vehicles in Cologne (FRG). The engine wear is in all engines as low as in comparable diesel engines. In passenger cars M 100 has shown high thermal efficiency and favourable exhaust gas emission values. Optimization of the engines is currently in progress. The use of special lubricant is required, because deposits in the inlet system and higher wear rates under low temperature driving conditions did occur. Presently a large scale "M 100 pilot programme" is conducted throughout Germany (FRG) under the guidance of the FMRT (Federal Ministry of Research and Technology). The final result will be available by the end of 1988.

4. The strategy of introduction for methanol as a motor fuel in Germany is now as follows:

4.1 M3 can be used for all motor gasoline absorbing the bulk of the produced and imported methanol.

4.2 M 100 for city buses and commercial fleets in large cities will be used in order to minimize supply cost and to optimise the profit in respect of reduction in air pollution in congested areas.

4.3 The increasing glut of methanol in the World market is expected to keep methanol prices low as compared to gasoline and diesel prices. The market in Germany will be balanced by the requirements of the M 100 fleets and the general gasoline market which can fluctuate between M 1 and M 3.

1. II. Suggestions for the development of the methanol market in India based on the experiences gained in German Field Tests

1. The requirements in India are different from Germany. In India, the <u>substitution of diesel fuel</u> by methanol is the most important target.

2. Investment cost for the supply system and for engine modifications must be reduced for India to the absolute minimum. Therefore, the use of methanol by fumigation (upto 25 % vol) into the inlet system of diesel engine, as developed by IIP (See* literature below) is the best approach to the problem as this system is flexible. Captured fleets should be converted to this system.

3. Introduction of methanol into the total filling station system is not advisable in India for the time being. The cost of cleaning and drying would be very high and it would be most difficult to organise the continuous supply of methanol to keep the filling station system clean and dry.

4. The use of methanol/gasoline mixtures upto M20 in two-stroke and four-stroke gasoline engines will raise problems on materials in the supply system as well as in the engines. It can, therefore, only take place in fleets which are modified carefully and fueled out of centralised stations.

<u>Literature References:</u>

* A.K. Singh, B.P. Pundir, Avinash Singh, Indian Institute of Petroleum,

"A Fuel System For Dual-Fuel Operation of an Automotive Diesel"- IV International Symposium on Alcohol Fuels, Guaruja, Brasil, Oct. 1980.

5. The development of methanol (M 100) engines based on diesel engines but using spark ignition (like MAN) or vaporisation and spark ignition (like Daimler Benz) or dual fuel system (like KHD and MWM) should be pursued in order to build up M 100 fleets in congested areas to reduce air pollution and save diesel fuel. This type of engine could also be exported later to countries which have cheap methanol like New Zealand and Malasia but no engine manufacturing industry.

6. As the first step fleet tests in city buses should be organised. The producer of the engines (Ashok Leyland and Tata) <u>must</u> be involved in these tests. Cities like Madras and Bombay could be the test areas since methanol could be imported to these harbors cheaply. As India will have to import diesel fuel ($\sim$6.4 million t in 1985) anyway, this methanol import would not alter the balance of payment since it would replace diesel.

1.2.1 Results of Discussions after the 2 Lectures LUBRICATION OF M 100-ENGINES

(Full text see Part C - Appendix 2)

1. For methanol engines derived from diesel engines = like Daimler Benz-MAN-KHD- bus engines = suitable Motor Oils are available. Low wear figures have been obtained in long term field trials.

   As for India the replacement of diesel fuel by methanol has first priority it seems necessary to establish first a suitable motor oil in an Indian built diesel engine converted into a methanol engine.

1.2.2 Recommendation on lube oil development for methanol engines for India

1. Historically, laboratory tests used to qualify engine oils have been developed based on field experience. Lubricant performance deficiencies which have existed in the field can be demonstrated in these tests and development for improving the performance can be started in the laboratories. Since in India, no methanol field trials have taken place up to now, the experiences from other countries have to be taken as a basis.

2. To screen the lube oils available in India for its suitability in methanol engines two prerequisits are necessary:

   a) An Indian built methanol engine, which is giving reproduceable wear and performance results in relative short time.

   b) An engine lube oil, which has proven its suitability for methanol engines in a large scale field trial.

To fulfil these requirements the Kirloskar 1 Cyl. engine (see** literature reference page 26) has been set up as a standard methanol test engine. This was an urgent task for the project (see Part C Report by Dr. P.C. Nautiyal and A.K. Gondal).

3. Optimization of the combustion is the most important fact to obtain successful lubrication. It can be achieved in different engine types, as seen in the above lecture.

   To control the combustion in the Kirloskar AV1-Engine when running on methanol the temperature on the glowplug should be controlled closely. Special glowplugs with built in thermocouple have been obtained from Germany (FRG) for this purpose. They were used to optimize the combustion process prior to establishing the test conditions for lube oil evaluation (see Part C page 172 Report by Dinesh Kumar).

4. High engine wear occurred in methanol fueled engines, when cooling temperatures were low.

   Therefore, the test conditions for lube oil evaluation should be set accordingly. Cooling temperature of 40°C have been tried and stable running of the Kirloskar-Engine was achieved even with this low temperature level.

5. As soon as a well defined standard test procedure was established the reference oil "Formula 222A", which has given very good results in over one million miles of fleet testing in the USA (Bank of America) was run to obtain a "base line". (Results see Part C page 203 Report by Dr. P.C. Nautiyal/Mr. A.K. Gondal).

6. New engine lube oils composed from additives, which can be produced in India using the experience from

additive firms developing methanol oils for many years already, should be tested afterwards. By comparing the results with the "base line", it will be possible to establish a suitable methanol engine oil based on Indian components.

A second oil, which could be produced later by Lubrizol India Limited, Bombay = Code OS 70336 = is available to the project from LUBRIZOL USA. This oil has shown good results in the modified Ford VD engine test. It should be compared in the Kirloskar Engine against "Formula 222A" and the standard engine oil (Indian Production) as used by IIP upto now.

The best oil composed from Indian components should then be distributed to the engine manufacturers, who are developing methanol engines. If their engines are not running well on this oil, then the engine has to be developed further. The oil cannot overcome shortcomings of the engine.

** Literature Reference:

Dinesh Kumar, B.P. Pundir, Engines Laboratory, IIP, "Combustion and Performance Characteristics of a Methanol Fueled DI Diesel Engine", VI International Alcohol Fuels Symposium, Ottawa, May 1984.

1.3 Results of Discussions after the 3. Lecture

WEAR IN METHANOL ENGINES

(Full text see Part C- Appendix 3)

1. The protection against wear by improving the motor oil quality was shown in radioactive tests. This technique was also used successfully in a methanol fueled Ford-Pinto-Engine.

   As for the project in the IIP some experience exists in the radioactive wear measurement by using activated piston rings, the Kirloskar AV1-Engine should be used in this matter. It is important, however, that very stable engine running conditions are established before hand. If radioactive testing has started no extra maintenance is possible to the engine.

2. For laboratory screening tests some "glassware tests" have been described in the lecture.

   It will be helpful if the project is developing on the basis given in the lecture an apparatus to obtain blow-by condensate for laboratory tests. The composition of the blow-by condensate is an indicator of the quality of the combustion.

2. Personal discussions on details of the experience with glowplug - methanol - engines in Germany

2.1 On the basis of a detailed technical report, which is not yet published,-provided by Mr. G. Finsterwalder, Kloeckner- Humboldt- Duetz AG, Cologne, F.R.G.,- the possibilities of improvement of the Kirloskar AV1 engine for use with methanol fuel were discussed. The measurement of the glowplug temperature in the Kirloskar AV1 engine could not be performed accurately with the equipment available. Therefore, the expert requested help from MAN, Nuernberg F.R.G. (Mr. A. Neitz/ Mr. F. Chmela). These gentlemen have sent free of charge a special glowplug with built in thermocouple, which is now installed in the Kirloskar AV1 engine of the IIP.

2.2 Provision to change the projection of the glowplug in the combustion chamber is now made. By this measure, it should be possible to minimize the energy requirement for the glowplug and optimize its lifetime. This is important for lube oil testing, because no interruption should take place during a test run. (see Part C Report by Mr. Dinesh Kumar).

2.3 For further work to optimize the Kirloskar AV1 as a methanol engine the expert has suggested to Mr. Dinesh Kumar the following areas:

a) change in the glowplug positioning to reduce the heat loss to the cylinder head,

b) investigating the influence of cylinder liner temperature on combustion,performance and engine output (specific fuel consumption),

c) variation of the injection nozzle to put some of the fuel in liquid form on the wall of the bowl in the piston (reduce peak pressure).

3. Assistance to IIP staff for installing 1 Cyl. Kirloskar AV1 engine as a test facility for lubricating oil

3.1 The accuracy of all measurements taken during a lube oil performance test must be of high standard because otherwise the results might be not repeatable and therefore, worthless. All actions necessary were discussed and suggestions for improvements were put forward.

3.2 Since 7/5/85 the Kirloskar AV1-Engine is running in the Radio Active Laboratory as a methanol luboil test engine. Untill the 6/6/85 ten 50 hr luboil tests have been completed without major complications. There is plenty of room for improvement in respect of accuracy but the engine and the test procedure have shown its suitability for the envisaged task. (Test results see Part C, page 203. Report by A.K. Gondal and P.C. Nautiyal).

The 50 hr luboil test has rated the oils (Formula 222A, Lubrizol OZ 70 336 and IIP Type 3) in the expected order. The oils specially designed for use in methanol engines did show no increase in wear when using methanol as the fuel compared to diesel fuel.

3.3 The brake of this test stand has to be replaced or totally overhauled as soon as possible.- The positioning of the glowplug should be changed again if the further work by Mr. Dinesh Kumar is showing the possibility of improvement.

4. Assistance to IIP-staff for running lube oil tests in the Kirloskar AV1 engine

a) with methanol (glowplug)

b) with 25 % (vol) methanol by fumigation and diesel fuel.

4.1 As soon as reliable and stable running conditions of the Kirloskar AV1 engine was achieved, the lube oil testing has begun. It is planned to measure the engine wear under low temperature (~ 40°C cooling water inlet temperature) running conditions in a 50 hr test by determining the iron content of the used lube oil and the weight loss of the piston rings.

4.2 The engine cleanliness (Piston rating) is observed. A polished steel plate in the crankase will be used as an indicator of any corrosion on steel by the contaminated luboil.- The main bearing will be controlled for corrosion.

4.3 Detailed analysis on the used luboil are planned. Its results could be very interesting. They will, however, depend on the possibilities of the analytical section which is greately limited by the power supply situation. (Details see Part C, Report Dr. P.C. Nautiyal, A.K. Gondal).

4.4 In a second step this programme could be rationalized by using the radioactive tracer technique. The IIP has already done tests with radioactive piston rings some years ago. The permit to run such tests is now renewed since May 1985. Actions to obtain the required radioactive piston rings are in hand. A detailed time schedule for these tests, as proposed in the detailed work programme is given in Part C page 211 (Dr. P.C. Nautiyal)

4.5 To control the combustion during the luboil tests with radioactive rings a pressure pick up and an oscilloscope should be installed in the head of the Kirloskar AV1. Only if the combustion stays constant short term tests are possible.

Using the radioactive tracer technique could reduce the test time to 8 hrs for one oil. It would improve the value of the results because several oils could be tested in a series without dismantling the engine. Therefore, it is suggested that the project should make the effort to achieve this test possibility.

The delivery of the activated rings was expected for 24/5/85, but it is delayed.

4.6 The expert organized the supply of an engine oil (Formula 222A), which had been field tested over more than 1 million miles by Bank of America in California (USA). The oil was supplied free of charge for testing by Mr. M. Litton, Vice President World Trade BcA. This oil can be used as "base line" to compare the performance of other oils.

In order to involve the Indian Lube Oil industry the expert paid a visit to Lubrizol India Ltd., (LIL), Bombay (see Part C, Appendix 4). As a result, the Chief Technical Adviser of THE LUBRIZOL CORPORATION Wickliffe USA, Mr. C.C. Colyer agreed to supply a "Methanol engine oil" as successfully engine tested in the "Methanol Ford VD-Test", but based on components which could be produced later on in LIL, Bombay. A 5 gallon sample* of this oil (OS 59 853A)

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* (based on the additive package OS 66 893 A).

has been sent of by airfrieght from Wickliffe, USA on Feb. 25, 1985. A 113 ltr. sample based on the same additive package (OS 66 893A) but composed in Indian Oil Corporation base stocks has been sent by LUBRIZOL. <u>This oil "OS 70 336" should be regarded as the first choice for field trials</u>.

LUBRIZOL is prepared to sell this oil in India and will start production at LIL, Bombay as soon as the market demand is high enough. (Analytical data, see Part C page. 200.).

5. Report and discussion on laboratory screening tests

5.1 This task was fulfilled with the 3, Lecture (see Part C, Appendix 3). Discussions on this matter were continuing on a personal basis with those IIP staff members interested.

5.2 A fuel inhibitor (Metacor 704), which had proved to be successful in field tests with Bank of America was handed to the project by the expert. This material has shown very good results in a laboratory screening test developed by IIP (Details see Part C page .181. Report by Mr. A. Jayaraman).

Two further fuel inhibitors for methanol fuels, developed by Du Pont (USA) and approved by EPA, Washington, are called for by the expert. It is expected that these materials, which are commercialised only in Feb. 1985, will arrive with the project soon.*

6. Assistance to IIP-staff for setting up laboratory screening tests

(See under 5).

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* The samples have arrived in the 1st week of June at IIP.

7. Assistance to IIP-staff for formulating methanol engine oil by using additives available in India

This task was fulfilled by the visit to Lubrizol India Ltd (see Part C, Appendix 4, Visit Report) and by lectures 2 and 3. The discussions are going on with those IIP staff members interested. More, active work will be possible when the engine test work is evaluated.

8. Explaining and suggesting to IIP-staff a system to developm prescreen and engine test luboils

8.1 A basic management concept is necessary to develop successfully and economically engine lubricants. The technological effort at the laboratories and engine test beds has to be guided and organized from input generated in the practical field of application, the motor industry and the oil-/additive industry.

8.2 Field problems like high wear or engine break down due to deposits have to be identified first in detail. Continuous cooperation on these questions with well organized customer groups in the field is the best base to obtain the required data and facts. In order to cover all engine types and service conditions these groups would be:

bus fleets (city- and long distance)
taxi fleets (city- and long distance)
commercial transport fleets.

In order to obtain their cooperation some benefit must be obvious to these fleet operators for the effort they have to put into the oil sampling and reporting scheme. To optimize the engine life time, to minimize the fuel consumption, to improve engine reliability and to optimize preventive maintenance should be the goals of the scheme. In regular intervals the results in this respect have to be recorded and discussed.

In this atmosphere of cooperation to the benefit of <u>all</u> partners an open discussion on all difficulties is easily possible. If problems occur which could be related to the lubricants performance the background data are available. In such a case the engine manufacturer and the lubricant supplier has to be invited to participate in the discussion.

8.3 <u>The identification of the problem</u> should be a joint effort of the fleet operator, the engine manufacturer, the oil supplier and the IIP as "catalyst" in this round. The theoretical causal connection and the chain of causation has to be taken in consideration. If the problem has become clear the IIP can and should suggest an engine test in the laboratory which is showing similar results - e.g. deposits at certain points - under similar service conditions. The test conditions - e.g. temperature level - have to be adjusted to represent the practical conditions in the field.

8.4 The <u>engine oil development</u> can then start in the laboratory. The fastest way of solving such problems is to run experimental oils prepared by the additive manufacturer. They know best, which component in the additive package should be changed. Since, there are many chemical and sometimes physical interactions within the package when changing one component, it is not advisable just to add some new components without knowing the rest of the package in detail. Detrimental side effects can occur.

Before starting engine tests with the new oil some routine test on oxidation stability, corrosion protection and emulsifiability should be done in glassware. If measureable deterioration in these aspects is observed, some further changes are required before engine testing can commence.

8.5 Some field testing is required after the 'new' oil has shown good results in the engine test laboratory. In western countries the oil- and additive companies as well as the engine manufacturer have well controlled test fleets for this purpose. This is rather costly but necessary to protect the bulk of the customer.

The control of 'new' oils in field trials requires much more details on running conditions, fuel quality and driver behaviour than 'normal' fleet tests. The engines have to be dismantled and inspected in great detail by specialists. A lot of experience is needed to evaluate these engines. Therefore, a close cooperation between the engine manufacturer and the oil-/additive supplier is recommended.

8.6 The role of IIP in the development of 'new' oils can be a 'management' and a 'working' position.

First of all, a collection of field data (see 8.2) has to be organized. Since IIP has large analytical and engine test facilities available, which are not fully utilized, a service could be offered to fleet operators. As soon as a continuous power supply with constant voltage has been arranged the capacity of the analytical and engine test facilities at IIP will be multiplied.

The charges to the fleet operators for analysing and evaluating oil samples could be kept very low and therefore attractive if large groups of samples are processed in the modern equipment of IIP. All the data could be processed by the computer of the engine lab and used as a data bank for future developments.

This data bank would be an interesting and valuable asset for discussions with the motor and the oil-/additive industry. All these partners will be pleased to cooperate with IIP if this sort of real field data can be provided.

Fast analysing and data reporting can be achieved by strict organisational measures. The expert has run methanol field trials in buses in New Zealand, but guided on laboratory results obtained in Hamburg(FRG). Airmail and Telex communication made this cooperation possible.

IIP will scarcely have the opportunity to develop engine lubricants on its own, but it should be involved in many of these developments as a partner. By this built up of experiences IIP could become in the long run <u>the</u> authority for lube oil development in India.

9. Discussion on additive development for two-stroke engines running on methanol or methanol blends

9.1 The theoretical basis for this task has been established by the lectures. For practical tests a two-stroke methanol engine oil from Lubrizol (OS 59 770) is now available at IIP. This oil is fully mixable with neat methanol.

9.2 Before further development for 2-stroke methanol engine oil takes place a decision on the fuel composition should be taken since the basic approach in lubrication will depend on the fuel, whether it is neat methanol, a mixture of more than 50 % of methanol with gasoline or a mixture of less than 50 % methanol with gasoline.

9.3 Neat methanol requires an fully mixable (soluble) oil. Only synthetic base stocks like polyglycols can be used. LUBRIZOL OS 59 770 is such an oil. LUBRIZOL OS 53 434 F, as supplied in 1984 to IIP, is similar. OS 53 434 F gave a lot of black sticky deposits in the carburettor during the tightening/seizure test. Ideling bore became blocked. In the next test OS 59 770 was tried but with the addition of "Additive W", which was supplied by the expert. The carburettor stayed absolutely clean. This first development step indicates that the problem of inlet deposits can be overcome, but further optimization is required. As soon as patent coverage for "Additive W" has been obtained this optimization can be started (Details of tests see Part C page.190. Report by Mr. Mukesh Gupta).

9.4 Castor oil can be used for neat methanol also. It has shown good lubrication properties but it is a natural product with variable quality. This has led to the fact that castor oil is used for trials to keep the engines running only. For racing engines, which sometimes use methanol mixtures as a fuel, castor oil or lately synthetic castor oil has been used. But more modern racing engines are using mineral based oils since the engine cleanliness could not be obtained with castor oil.

A lot of development on base oil quality and suitable additives would be required if castor oil would be chosen for the lubrication of methanol engines.

As an interim measure it has been used and can be used for combustion studies in methanol 2-stroke engines. It cannot be used for exhaust emission test since it is giving eye irritating fumes.

10. Assist IIP-staff on evaluation of newly developed two-stroke additives in engine tests.

10.1 The IIP-engine laboratory has tried in 2-stroke engines a methanol fuel containing the corrosion inhibitor Du Pont .... This showed a reduction in deposits and ring wear. A repeat of this test and the evaluation of further additives is recommended.

10.2 The expert brought alongwith him the fuel additive "Metacor 704" which had shown good results in California (Bank of America). The "Metacor 704" showed better results in the IIP-laboratory corrosion test than the Du Pont .... Therefore, it should be engine tested in comparison.

Two further Du Pont-Additives (DC 1-11 and DG 01-100) are on the way to Dehradun for testing at IIP.*

If clearly measurable wear reduction can be obtained in engine tests by using these fuel additives, which are basically developped to prevent corrosion in storage and fuel lines, then a basic research programme in this field could be started. A well equipped metallurgy group would be needed as a partner in such a programme.

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* Technical details see Part C, Appendix 5a and 5b.

Part C: APPENDICES

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
UNITED NATIONS DEVELOPMENT PROGRAMME
Assisting : INDIAN INSTITUTE OF PETROLEUM

APPENDIX 1

ADDRESS FOR CORRESPONDENCE :
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Your Ref.

Our Ref. IND/82/001/..05

IND/82/001–APPLICATION OF ALTERNATIVE
FUELS FOR INTERNAL COMBUSTION ENGINES

Lecture held by Hans-Christian Wolff
at the Indian Institute of Petroleum at Dehra Dun
on Thursday 3. Jan. 1985

"German Field Test Results on Methanol Fuels M 100 and M 15"

Abstract

From 1979 to 1982, 22 industrial companies (including 8 oil companies and 8 engine manufacturers) and 15 scientific institutes investigated the use of M 15 and M 100 in field tests within the scope of a DM 110m programme financially supported by the FMRT. 30 stations for M 15 and 15 for M 100 were set up across the Federal Republic of Germany. 989 vehicles were tested in day-to-day driving. One result may be stated definitely: The production and operation of M 15 vehicles are technically possible. A prerequisite herefor would be setting up a comprehensive M 15 station network. The technical preconditions are known.

M 100 demonstrated a high degree of thermal efficiency in private motor car engines and favourable exhaust gas emission values. Optimization of the engines is currently in progress. The lubricating problems (wear in cylinders and deposits in the inlets systems) have not been satisfactorily solved yet.

The M 100 engines for commercial vehicles/buses were developed from diesel engines. They have attained the same high degree of thermal efficiency as diesel engines. The exhaust gas emission is free of soot and favourable with respect to NO_x content. The wear and tear problems with buses in city traffic have been overcome.

34 references.

The following is the full text of the prepared lecture which was presented in a shortend form over 2 houres.

Contents

1. Introduction

Fuels manufactured from petroleum will remain abundant for a considerable time. Their price, however, has risen so drastically within the last ten years that methanol has now become competitive with reference to its calorific value in some parts of the world where, for instance, it can be produced from otherwise hardly utilizeable natural gas.

Methanol may also be considered as one of the liquid fuels to be produced from coal, as large-scale industrial coal gasification plants have now reached a high level of development.

The most important development goals being pursued by motor car manufacturers are a favourable degree of thermal efficiency and minimal amounts of pollution in engine exhaust gas. Methanol can be employed as a fuel to help reach these goals.

The development of new engines for methanol fuels demands close cooperation between motor car manufacturers, fuel suppliers and scientific institutes employed in basic research. The testing of new engine concepts in practical operations by normal consumers is an important step. Not until the results from such demonstration projects are evaluated will the government be able to render well-founded decisions (e.g. fiscal policy). The Federal Ministry for Research and Technology (FMRT) has therefore promoted and financially supported this joint research in order to demonstrate to industry that the state is interested in a long-term, secure, economic supply of fuel.

This joint research does not damage competition among the companies involved. Through a neutral coordination of all results by the project monitoring group (Rhineland Technical Control Office) called upon to do so by the FMRT, the value to the national economy and thus the protection of the individual company from misinvestment are assured.

The investment decisions that might then become necessary on the part of industry for the production of new engine designes and the change of the fuel supply infrastructure can thus best be safeguarded.

2. Scope of the Programme

The objectives of the FMRT alcohol fuels programme are:

- Testing of engine concepts for M 15 and M 100.
- Testing of infrastructure (transport,storage, filling stations).
- To ascertain the reaction of the public to changes in driving characteristics etc.
- Related investigations concerning environmental, health and safety matters.
- Promotion of the scientific development of methanol utilization in engines.

Fig. 1 shows an organigramme of the FMRT Project.

The following vehicles have been employed under practical road driving conditions:

- 981 passenger cars, 890 using M 15 and
  81 using M 100
- 8 buses and trucks, all using M 100.

For supply purposes a distribution system was established comprising

- 30 M 15 filling stations and
- 15 M 100 filling stations.

The following companies/institutes took part:

8 oil companies
3 chemicals companies
8 engine manufacturers
3 accessory manufacturers
22 industrial companies.

15 scientific institutions
and research institutes.

Hundreds of used oil samples and many fuel samples from field trial cars were investigated in order to have an early indication as to whether heavy wear or other engine trouble was to be expected. The results of these samples were compared with results from samples taken from engines operated in laboratories. This measure helped to confirm that the engine tests conducted in the laboratories actually did indicate the difficulties which occurred in practice.

The exhaust emissions and fuel consumption of a number of M 15 cars were examined at the beginning and end of the test programme in order to detect any deterioration which may have occurred during 3 years of practical driving.

The driveability and handling characteristics of a number of M 15 cars were determined under different ambient temperature conditions on fully airconditioned vehicle dynamometers. These results were compared with the numbers and details of complaints coming from field trial customers. This procedure ensured that the test methods employed in the laboratories actually did reflect practical operations.

In the period from 1979 to the end of 1982 a total of approx. DM 110m was spent by all participants. The FMRT has taken over approx. DM 58m of this (2).

3. Results on M 15 (14)

All German motor car manufacturers took part in the M 15 programme of the demonstration project. The numbers of the vehicles used are:

M 15 Test Fleet (14)

Manufacturer	Types	Total number (planned)
BMW	1	10
Daimler Benz	2	40
Ford	4	180
Opel	2	200
Porsche	1	11
VW-Audi	6	600

The individual motor car companies participated in this part of the project with the following concepts: (14)

Bayrische Motorenwerke AG (BMW), Munich, provided its model BMW 732 i. By modifying the electronic injection system (Motronic) used here, it is possible to store Lambda and ignition timing performance characteristics for M 15 as well as premium fuel and thus optimize performance, fuel consumption, exhaust emission and driving characteristics for both fuels. In addition, the fuel system pressure was increased in a basic motor that remained unchanged vis-à-vis the series, to take into consideration the volatility of M 15 fuel.

Two types of vehicle were employed by Daimler-Benz AG, Stuttgart.

The 230 E motor car has an injection system adapted to the air ratio; in addition, a catalyst with a self-entraining air supply is used. Exhaust emissions are thus reduced markedly so that when the M 15 design is operated with premium fuel, the exhaust emissions remain clearly below the limiting values permitted.

The second design provides for a van (LT 601) with a carburettor engine. Here, both the carburettor and fuel system have been modified to take the air requirements and volatility of M 15 into account.

Ford Werke AG, Cologne, employed the following models: Fiesta, Taunus, Granada and Escort. All of these models are carburettor vehicles with modified material specifications for those parts that come into contact with the fuel. The carburettor setting was adjusted.

Adam Opel AG, Rüsselsheim, employed its Rekord with a 2.0 l HC-engine, partly as an injection vehicle with L-Jetronic, partly carburettor equipped. Besides material selection, the modifications compared to the normal assembly line products mainly involve adapting the air ratio and modifying the fuel system with the carburettor vehicles.

The company, Dr.-Ing. h.c. F. Porsche AG, Stuttgart, selected its model 924. Here, a new motor design with high compression was used ($\varepsilon = 12.5$) with an adapted injection system. The fully electronic ignition system provides for switching to various ignition performance characteristics - M 15 or premium. It is thus possible not only to operate the vehicle on both fuels smoothly with respect to driving characteristics, but also to fulfil the ECE-R-15 exhaust values valid for 1980 with both fuels. An advanced development of this vehicle additionally provides for using regular.

A total of six different vehicle types, private motor cars and small vans were employed by Volkswagen AG, Wolfsburg and Audi-NSU AG, Ingolstadt. The selection of the models was with a view to including all interesting carburettor and injection systems in the test. The vehicles were to correspond as much as possible to the current assembly line models. The mixing system was adapted to the air ratio for operating on M 15 and the cold start equipment partly modified. The fuel supply system was remodelled, taking into account the greater volatility of M 15. In order to improve driving characteristics, particularly when the engine is cold, all of the vehicles were equipped with an electronic ignition system with DLS (digital idling stabilization).
The relatively large number of VW vehicles was also aimed at contributing towards a corresponding throughput at the various stations, a necessary prerequisite for testing the oil companies'

distributing and marketing systems. - In addition, close cooperation with accessories firms, particularly carburettor and injection system manufacturers, was aimed at in order to pass on the experience of the programme direct.

3.1 Fuel Specification M 15

In order to obtain genuinely comparable results throughout the duration of the test, it was important to have constant fuel quality at all operational locations. For this reason, one supplier was chosen for the grade to be used in summer and one for that to be used in winter.

The water tolerance was set with TBA so that no phase separation occurred up to 1,500 ppm water content in summer to 0°C and up to 1,000 ppm water content to minus 15°C in winter.

It was decided during the course of the demonstration test to use a detergent/corrosion protection additive package normally found in branded gasolines in Germany, although DIN (German Industrial Standard) 51600 does not demand this. Thus, comparability with normal branded premium fuel was established. - It was determined in the Opel Kadett test that the quantity of detergent had to be more than doubled to obtain with M 15 the same cleanliness in the entraining system as with regular (15).

All other characteristic data were specified in line with DIN 51600. (Cf. Table 1 - that also shows the actual field data) (4). Only the distillation range and vapour pressure could not be maintained according to DIN 51600, owing to the use of 15 % by volume of methanol. Fig. 3 shows the deviations (3).

This M 15 specification proved itself in practice.

3.2 M 15 Driveability / Performance / Consumption

Consumers will only accept new fuels such as M 15 if no noticeable disadvantages in driveability can be ascertained. In order to be able to compare the values determined for "hot fuel handling" and "cold weather driveability" in the fully air-conditioned vehicle dynamo-meter, they were compared with complaints made by customers during the field test (5). There was considerable conformity, thus proving that the results obtained at the vehicle dynamometer are practical.

At an ambient temperature of 20°C, all M 15-engined vehicles show hot fuel handling characteristics equivalent or superior to those of gasoline-engined cars.
As shown in Fig. 4 (5), above 30°C some of the M 15 versions of the

engines tend to be inferior to corresponding gasoline engines with respect to acceleration (hot fuel handling).
At 35°C, however, 65 to 75 % of the M 15 cars demonstrate inferior characteristics, depending on the volatility of the gasoline used for reference purposes.

Most of the M 15-engined vehicles were significantly inferior to average branded gasoline driven cars with respect to cold weather driveability at ambient temperatures of between minus 10°C and plus 5°C, as shown in Fig. 5 (5). Compared to a gasoline of borderline quality (DIN 51600), however, only approx. 40 % of the M 15 cars demonstrated inferior performance at minus 10°C; indeed, 40 % of the M 15 cars were superior.

As was anticipated, vehicles with fuel injection engines showed no difference.

It must be borne in mind that the car industry has had relatively little time to develop engines optimized for M 15. The weaknesses could be eliminated without greater difficulty in the course of developing engines for mass-produced units, provided that adequate time and funds were made available.

It can be seen as an example from the results obtained from the Porsche 924 vehicles that good performance is possible in cars designed especially for M 15 (6). Fig. 6 shows that the M 15 version is better with M 15 (Mode a) than with premium grade gasoline (Mode c) with respect to maximum speeds, acceleration and elasticity.

Fig. 7 shows how optimizating the motor (ε = 10.5) for M 15 can increase performance across the whole RPM range, employing a Daimler Benz 230 E as an example (engine type M 102) (7).

Fuel consumption is an important factor affecting economy. It depends heavily on the degree of optimization of the engine. - The statistical mean value of volumetric fuel consumption increase determined in October 1982 as an average value for all M 15 vehicles employed in the FMRT programme was 5.6 % by vol.

Especially highly optimized engines, such as those mentioned above, finally no longer even demonstrated any increased volumetric fuel consumption. In these models, therefore, the thermal efficiency of the engines had been increased markedly.

It must be stated, however, that the engines optimized for M 15 could not automatically be operated on premium. In this case, the exhaust emissions were considerably less favourable. Vehicles equipped with a switchover device M 15 ↔ Super are being tested - but the expense is considerable.

3.3. M 15 Lubrication and Wear

Since the goal of the M 15 Demonstration Project was to test vehicles driven by customers in normal everyday traffic, four good, easily obtainable branded engine oils were used for the M 15 fleet. They had the following quality specifications: (8)

Oil	Viscosity	Performance level
W	SAE 30	API SE/CC
X	SAE 15 W-50	API SE/CC
Y	SAE 15 W-50	API SF/CC
Z	SAE 15 W-40	API SF/CC

Table 5 Engine Oils for M 15 Fleet Test

Following laboratory experiments with 4 different M 15 engines in a test run simulating 5,000 km of city driving conditions, these oils were released for the fleet test, as no lubricant-induced difficulties were to be expected in the short term.

The test cycle - see Fig. 8 - was agreed between the engine manufacturers and oil companies. It consisted of 62 % driving and 28 % idling, and can thus be designated as extreme, but not unrealistic. The coolant temperature fluctuated between 40 and 60°C. Between 45 and 55°C were measured in the oil sump.

During the further course of the fleet test, 200 vehicles were monitored by means of constant used-oil sampling. (9) Each oil company appraised the lubricant oils that it had supplied. The testing methods were the same for all of the companies in order to obtain a uniform data pool for the final evaluation.

The initial results obtained from vehicles with especially high mileage (fast runners) did, it is true, show somewhat increased Fe and Cu values - Cf. Figs. 9 and 10 -, but no modification was made to the lubricating oil formulations, as the scheduled operating period of 3 years did not appear to be in danger. This proved to be correct. At the end of 1981, reports were presented on 112 M 15 vehicles that had driven a total of approximately 5m km (10). No breakdowns on account of lubricating oil were registered, although many of the engines had been operated for more than 120,000 km.

The Fe content in the oil drained off after a normal oil change interval, corresponding to the specifications of the engine manufacturer, balanced out in the privately driven vehicles - i.e. no fast runners - between 30 and 80 mg Fe/kg oil. The Cu content in the oil drained off, that first fluctuated between 10 and 70 mg/kg, only attained a level of 10 - 40 mg/kg following operating periods of approx. 35,000 km/vehicle (10).

Final results on wear figures are not expected until a more detailed examination can be made of the engines that are to be taken apart and scrutinized at the beginning of 1983.

3.4. M 15 Fuel Distribution

The M 15 fleet test was concentrated in Berlin where 11 stations were equipped for dispensing M 15. In order to obtain a comprehensive network for the whole of the Federal Republic, a further 19 stations were selected so that M 15 vehicles could drive throughout Germany without "premium refuelling" (see Fig. 2). All test participants received a special mini-atlas with exact road maps allowing them to easily find the M 15 stations.

Each participant received a magnetic card which he had to insert into a control device when fuelling. Not until he had additionally entered into the control apparatus the vehicle mileage and any "premium fuelling" that had been done, was the pump released. Thus, all fuelling data was electronically recorded and passed on for central evaluation at SNV Berlin. By the end of 1982, this "tank card data file" contained just under 2 million individual pieces of information.

The production (blending) was done in batches of 1,300 m^3. Following transshipment via rail tank cars, the fuel was stored in fixed-roof tanks (11).

The stations themselves were supplied by a central depot employing a 36,000-l road tanker in order to guarantee constant quality for all test participants. The central production unit was switched every 6 months (summer/winter).

The M 15 at the pumps was quality-controlled at regular intervals, before and after topping up the underground tank, in order to detect any bottom phases that might have occurred (alcohol/ water) (4). All of the tanks and pipelines, as well as the pumps, were new. Some of the underground tanks were lined with epoxyresin based Permatex HSA 2807 (33). This is important; for it is well-known that as little as 1 - 2 % by volume of methanol in fuel can cause rust to break off which will then easily clog the filters. For this reason, supply networks operating with methanol fuels must constantly be further supplied with fuels containing alcohol or thoroughly cleaned before use of methanol is resumed.

Tanks and fittings made of aluminium alloys Al Mg 4, Al Mg 3, Al Mg Mn 4.5 did not show any corrosion with M 15 (33). However, other aluminium alloys did show corrosion attack and should be protected.

Gummy residues only occurred at the beginning in certain stations - up to 300 mg/kg in the first litre taken from the M 15 pump (33). The residues were softeners from the pump hoses. Although these were resistant to M 15, they first released small quantities of softener until the inner surfaces had become "passive" with increased throughput. The vehicles were not brought to a halt on account of these gummy residues in the M 15, because only that small amount of fuel that had remained in the hose contained the softener.

The injection units on a number of engines demonstrated a proneness to very fine mechanical impurities (rust). It is consequently necessary when employing M 15 to ensure that the finest filters possible are used in the whole system.

3.5. M 15 Exhaust Emission

Only in vehicles equipped for M 15 could satisfactory exhaust gas values be obtained when employing M 15 as a fuel. If these M 15 engines are operated on pure premium, then the exhaust gas values are often outside the prescribed limiting values - if no devices for adapting the ignition and injection units have been installed.

In order to compare practical results and experiments on the vehicle dynamometer, one such stand was set up at both the Technical University and Daimler-Benz's branch workshop in Berlin where the greater part of the test fleet was being operated, for series experiments for exhaust gas tests according to ECE 15/04 and fuel consumption measurements according to DIN 70 030 (12). Measurements taken on 12 vehicles of the same family show that the modified formular for calculating fuel consumption from emissions also provided satisfactorily exact results for alcohol fuels as well (13) - see Fig. 11. Since fuel consumption in the ECE hot test and fuel consumption on the street were in the same order, all of the results may be designated as practical and relevant.

Fig. 12 shows that the emissions from 3 vehicles of the same family are very close and that there are hardly any changes even with an operating period of more than 50,000 km (12). As expected, there are considerable differences between various vehicle models with respect to exhaust emission data. Based on an average of 16 different engine models from 6 different car manufacturers, operations with M 15 result in relative improvements compared with gasoline operations - as shown in Table 6 (14).

The attempt to further improve M 15 vehicles by using catalysts in exhaust emission resulted in a marked decrease in catalyst activity after 20,000 km, as the basic M 15 gasoline contained 0.15 g Pb/l (12).

3.6. M 15 Customer Acceptance

The M 15 fleet test was a demonstration in which representatives from all groups in society participated. In order to achieve this and to ensure a continuous flow of reliable information (see 3.4 tank date file), the customers' additional costs were taken care of and an incentive offered for continuing through the whole test run. The private customer had to purchase the vehicle at the normal list price, but received a rebate after the first year of 3.0 %, 4.5 % after the second and 7.5 % after the third - a total, therefore, of 15 %.

The M 15 fuel had to be paid immediately at the station at the full price for premium demanded at the station. It was possible to determine through the electronic reporting of tank data whether the customer was in the normal range expected for the test. If this was the case, then a rebate of DM 0.10/l of M 15 fuel filled was given at the end of each month for vehicles that normally operated on regular. For vehicles that normally used premium, the fuel rebate was DM 0.05/l. In addition, a further DM 0.03/km was allowed for each test kilometre driven.

If there were irregularities, payments were stopped and queries made to clarify the matter.

At the end of the demonstration (Dec. 1982) all vehicles were reconverted to regular fuel. This was done for the customer free of charge. Thus, the exhaust gas emission laws were taken into account and the engine manufacturers, as well as the oil companies, were given an opportunity of obtaining "interesting" test engines by exchanging them for new ones.

This procedure was gladly accepted by all of the participants. They felt that they were being justly treated. Driveability and breakdowns were reported critically, but honestly, so that the car manufacturers were quickly able to detect weak points and remedy them.

In summary, it may be stated that optimized M 15 vehicles would be accepted by consumers if the slight additional cost of purchase (approx. 2 %) was at least offset by other advantages (fuel prices, taxes). An important prerequisite would be a really comprehensive supply infrastructure; this would mean at least 1,200 well distributed stations for West Germany.

4. Results on M 100

4.1. M 100 Fuel Specification

In order to provide car manufacturers with as secure a base as possible for costly M 100 engine developments, the fuel specifications for M 100 were laid down jointly, taking into account the aspects of availability, safety and costs.

Chemical grade methanol is a grade traded throughout the world and was thus regarded as being most readily available. The characteristic data are given in Table 2.

Safety demands made it necessary to add lower boiling hydrocarbon fractions, in order to constantly have a non-explodable fuel vapour/air mixture in the car fuel tank above the liquid fuel (11). This demand corresponds to the basic specification for methanol fuel M 100 (Cf. Table 3).

This safety requirement was first met by adding 8.5 % iso-pentane. This also had the advantage that cold starts were facilitated considerably.

For cost reasons, however, a replacement for expensive iso-pentane was sought. In October 1982, the specification detailed in Table 4 was agreed whereby iso-pentane was replaced by a C_5 cut and butane.

Aluminium, copper, lead and zink are heavily corroded by methanol. In the case of steel, normal St 12 demonstrated the most favourable values, particularly if water can be prevented from entering.

No decision has been reached as to the addition of anti-corrosion agents - and possibly detergent additives as well. They have not been used to date because, on the one hand, satisfactory effectiveness has not yet been determined and, on the other, there are unfavourable side-effects, e.g. reactions with the luboil. The search for suitable additive combinations is being continued but is very difficult, because the side-effects also depend upon the various engine designs and lubricating oil formulations. Here, only joint research will be able to help us further.

4.2. M 100 Passenger Cars

Daimler Benz and VW provided passenger cars for the M 100 project.

Daimler Benz selected its 2.8 l - 6 cylinder injection engine (ε = 9.1) (15) (20 units). In addition to the requisite changes to the fuel supply parts and the engine injection system, particular attention was also paid to exhaust emission and consumption results with and without catalysts. Considerable value was attached to cold starts and good driveability. A switch-over to M 15 or normal premium is not possible. In addition to the 20 vehicles selected for the fleet test, intensive work was carried out on an optimized engine version(ε = 12) for M 100.

VW selected the 1.6 l - 4 cylinder carburettor engine (70 units) and the corresponding injection engine (15 units) for its Golf vehicles. For its transporters (15 units) the 2.0 l-double-carburettor engine was used (16).

The combustion chamber had to be changed in the Golf 1.6 l-carburettor motor (ε = 12.5), as the sparking plug could become wet with cold starts. In return, a minimal diminution of maximal power output had to be accepted.

A greater number of series components were able to be used in the Golf 1.6 l injection engine (K Jetronic) (ε = 12.5), because it was not necessary to prewarm the entrained air or mixture. In the maximum power range, however, the output had to be cut back a little in order to avoid high-speed knock and pre-ignition.

The Model 2, 2.0-l engine with 2 carburettors, as an air-cooled horizontally opposed engine (stroke/bore = 0.75) can only obtain a compression of ε = 10.5 due to its combustion chamber configuration. Heating was provided for the entraining system and the fuel/air mixture in order to guarantee cold starts.

4.2.1. Driveability / Performance / Consumption

The Daimler Benz M 100 vehicle, Model 280 SE (15), was equipped with an electrically heated cold-start device - Fig. 13 - guaranteeing starts at-25°C; 8 % iso-pentane was used here in the M 100 fuel. When using pure methanol, starting at temperatures as low as -15°C is guaranteed. When starting cold and during the warming-up phase, the damming disk in the injection system is controlled by a solenoid so that practically the same operating conditions are attained as with a gasoline vehicle.

The performance can be increased considerably by raising the compression from ε = 9.1 to ε = 12 (see Fig. 14). Even with a motor of normal compression (ε = 9.1), using M 100 increases performance by approx. 5 % compared to premium.

Consumption can be reduced markedly through optimization, as shown in Table 7 (15). In practical operations, measured for 5,000 km, fuel consumption fell from 470 MJ/100 km in a normal-compression M 100 engine (ε = 9.1) to 421 MJ/100 km in an optimized (ε = 12) engine with an exhaust catalyst.

The Volkswagen M 100 engines were designed so that while driveability remained as good as with gasoline vehicles, especially the partial-load consumption of the M 100 vehicle was favourable. Fig. 15 shows the performance and consumption curves for the 1.6-l carburettor engine (16). At ~ 12 % higher performance, markedly lower specific energy consumption is recorded. At maximum speed (160 km/h) the improvement is approx. 19 %, in the partial-load range at 90 km/h it is approx. 18 %.

4.2.2. M 100 Lubrication and Wear (Passenger Cars)

Lubrication is of decisive importance for the life and operational reliability of engines. Thus it also contributes considerably towards the economical value of an engine design. Just a few months after the start of the fleet tests, it became quite clear that the hitherto best known lubricating oils would not be sufficient for the M 100 vehicles under all operating conditions.

Heavy deposits appeared in the inlet system where blow-by gases come into contact with methanol. These deposits finally caused engine failure through sticking, e.g. of the throttle blades. Trouble also occurred with the injection motors because deposits formed on the jets, causing a change in fuel distribution to the individual cylinders. In the worst case, a piston burnt out during a test stand run, because it had been operated so lean that extreme high-speed knock occurred.

High metal values were established in the used oil analyses, especially in the case of engines that had been driven cold. A mixture of corrosive and abrasive wear is obviously responsible here.

In spite of these problems, the fleet tests were not interrupted. The lubricant suppliers provided special oils with which an improvement in engine cleanliness was attained by reducing or eliminating the VI improvers and ashless dispersants. At the same time, the dosage of the anti-corrosion agent and anti-wear additive was increased. Synthetic basic oils were also employed. These, however, only proved themselves when the additive package was also adjusted to these basic oils.

In addition to these "ad hoc solutions" that made it possible to continue the fleet tests, systematic lubricating oil development was also carried on in the test stands.

Table 8 (17) shows that the average rust rating in the II D test is clearly worse with M 100 than with gasoline. In the III D test, cleanliness and oil thickening were not critical, but cam and lifter wear was higher than with the reference fuel and the wear on the cam shaft thrust washer was outside of specification. The use of M 100 in the V-D test resulted in cleaner pistons and better varnish rating, but once again cam wear was significantly higher than with the reference fuel and well above SF limits.

The Petter W 1 high temperature test did not provide any results that would indicate problems with M 100.
The Cortina high temperature test with M 100 gave an excellent result in terms of piston cleanliness and ring-sticking (Table 8), but heavy black deposits were formed in the inlet system.

In the VW 1302 test (18), too, piston cleanliness is better with M 100 than with the reference fuel, but the iron content in the waste oil is approx. 5 times as high with M 100 - see Fig. 16.

Since most of the M 100 vehicles did not start running until 1981, there are not enough used oil analyses available to allow conclusions to be drawn that go beyond the above in passenger cars.

At present, the results may be summarized as follows: (17) (18)

- M 100 improves piston cleanliness and average varnish rating,

- sludge formation with M 100 is higher under low temperature conditions compared to conventional fuel,

- M 100 fuel increases cam and follower wear,

- cylinder wear was found in some cases to be 10 times higher for M 100 compared with the reference fuel,

- inlet system deposits are a major problem with most M 100 engines,

- no suitable detergent additives for M 100 fuel are known at present.

The further development of optimized M 100 engines showed the following problem areas (30):

- cleanliness of the inlet system
- corrosion/sludge formation
- wear in cylinder/moving surfaces.

The above areas are being systematically examined at engine test stands. Attention is being paid to interactions between lubricating oil and fuel additives. It appears that the key to the solution is the lubricating oil (31).

The "city driving programme", known from the M 15 experiments (see Fig. 8), was varied with respect to coolant operating temperatures. Fig. 17 shows that there is no kink in the wear curve into the "high wear range" at coolant temperatures of between 50 and 70°C - normal ~ 50 mg Fe/kg oil; high range ~ 350 mg Fe/kg oil - throughout 173 operating hours (~ 5,000 km). At coolant temperatures of 40 - 60°C and especially at 35 - 55°C, on the other hand, a rapid increase in Fe content was observed right after approx. 60 hrs. when using good, conventional SAE 15 W/40 (API SF/CC) oils. The oil

temperature was approx. 55 - 65°C (31).
High RPMs and engine loads proved to be uncritical for wear in optimized M 100 engines.

The cleanliness of the inlet system could be improved by changing some additive components and increasing considerably the additive package in the engine oil.

Even though experimental oils of extremely high alkalinity (TBN approx. 30 mg KOH/g, ash content approx. 3 %) resulted in improvements with respect to wear and sludge formation, even under critical test conditions (35 - 55°C coolant temperature), this problem cannot be regarded as solved for practical operations, because the high ash content could trigger off other engine problems. Developments are continuing (31).

4.2.3. M 100 Fuel Distribution

Since the number of vehicles employed in the M 100 test was considerably less than with the M 15 demonstration project, only 15 dispensing units were set up - for reasons of cost. Fig. 18 provides an overall view of the distribution. The vehicles must carry corresponding amounts of fuel in reserve fuel cans for longer journeys, because the action radius of the M 100 vehicles could not be increased compared to normal ones, in spite of considerable enlargement of the tank.

An important factor is that all aluminium parts must be eliminated from the supply system because they are rapidly corroded by methanol. The resultant aluminium compounds form slimy residues on the filters. Aluminium compounds that pass into the combustion chamber are oxidized to form aluminium oxide (Al_2O_3) and then act as an abrasive on the moving surfaces, i.e. heavy abrasive wear occurs against which lubricating oil is ineffective (32).

The pump manufacturers were in a position to supply pumps and fittings that are resistant to corrosion through methanol or methanol/water. The chemicals industry does know suitable materials.

4.2.4. M 100 Passenger Car Exhaust Emission

The exhaust emissions from M 100 engines are considerably less than those of comparable gasoline engines. Given the same driving behaviour, the Daimler-Benz M 100 engines in the ECE 15 test demonstrated the following values (15):

Daimler-Benz 280 SE	HC * g/Test	NO_x g/Test	CO g/Test
Premium	8.6	12.5	86.5
M 100 (ε = 9.1)	2.6	6.5	52
M 100 + catalyst	2.5	2.7	18.8
M 100 optimized (ε = 12)	5.3	5.5	47
M 100 opt + catalyst	1.3	3.0	16.5

* measured with FID

The M 100 engines provided by the Volkswagen works also demonstrated very favourable exhaust emissions (16) of only

HC = 3.3 g/test
NO_x = 2.5 g/test
CO = 35.4 g/test

in the ECE 15 test cycle. Work is continuing on improving these values.

The exhaust emissions of the VW engine in the partial-load range (Fig. 19) are interesting, as the superiority of the M 100 engine is clearly shown (16).

One problem involves aldehyde emissions from motor cars with gasoline engines operating on alcohol. (28) At first, a suitable measurement method had to be developed. In the ECE 15 cold test, the aldehyde emission of methanol operated vehicles was up to 4.5 times greater than that of comparable petrol vehicles. In a warm operating condition, however, the emission is approx. 3.5 times as great.

The use of suitable catalysts could solve these problems - see Table 9 (28), mass-produced catalysts from the USA being very effective with methanol.

4.2.5. M 100 Passenger Car - Customer Acceptance

Since the performance and driveability of the M 100 vehicles is the same or better than corresponding petrol-operated vehicles, the consumers are satisfied with respect to these points. The cleanliness of the inlet system is still unsatisfactory, causing more trips to the workshop. The special lubricating oils that result in improvements in this area will probably be considerably more expensive than normal high-performance engine oils.

The wear behaviour is still unclarified, but will probably not bring about engine service lives comparable to those of gasoline engines until a considerable period of development has passed.

The tank sizes of the vehicles must suffice for at least the same action radius as with normal motor cars. A sufficiently close-meshed filling station network is another prerequisite. - The price of M 100 fuel must be fixed so that the volumetric overconsumption is compensated for; this will primarily be a question of taxation in Germany.

The additional costs for vehicle procurement will similarly have to be compensated for. The total cost per km must not be higher than with comparable gasoline vehicles in order to achieve satisfactory customer acceptance.

4.3. M 100 Commercial Vehicles/Buses

Unlike the passenger car engines, the development of M 100 engines for commercial vehicles/buses was based on diesel engines. Resort could be made here, in part, to earlier developments involving multifuel engines.

The following lines of development were pursued:

- External vapourizer for M 100 using waste engine heat, ignition with sparking plug - (Daimler Benz) (21) (22).
- M 100 vapourization in spherical combustion chamber in piston, following direct injection into each cylinder, ignition with sparking plug (MAN) (23) (24).
- Ignition-jet engine, injecting diesel fuel for ignition and employing methanol as a "working fuel" (KHD) - (25) (26) (27).
  The MWM and Volvo alcohol engines operate similarly; these, however, did not take part in the FMRT project.

The possibility of "converting" alcohol/diesel mixed fuels (29) and alcohol fuels with ignition improvers into diesel fuels was investigated. No report, however, can be made as yet as to the practical results within the scope of testing by customers in Germany. More results with ethanol and ignition improvers are currently obtainable in Brazil. (20)

4.3.1. M 100 Commercial Vehicles/Buses - Driveability/Performance/Consumption/Emission

From a technical and economic point of view, the supercharged diesel engine is particularly suited for long distance commercial vehicles. However, the use of M 100 in commercial vehicles will be especially favourable in congested areas because they are often characterized by traffic jams and air pollution.

Accordingly, the engines used in the FMRT M 100 test were operated in city buses in Berlin and Cologne (as well as in Auckland, New Zealand) and in street-clearing vehicles in Berlin. Here they were able to demonstrate their advantages in practical everyday operations. - (Similar results are obtained in Auckland, New Zealand.)

The cold startability is good for all engines. An external heater supplied out of the M 100 tank, which is usually available anyway for heating the passenger area, was employed in the Mercedes-Benz M 407 hGO engine (21). All of the engines running in the FMRT programme are quite clearly superior to comparable diesel engines with respect to driveability and performance (see Fig. 20, (21); Fig. 21 (24); Fig. 22 (25). Since high torque is attained at low RPMs, the accelation capacity - which is particularly important for the flow of traffic in city cores - must be designated as excellent. Under no circumstances is there any of the black diesel smoke that is so disliked as air pollution.

The partial-load control in all of the engines is so designed that they have a very high degree of thermal efficiency across a broad range. Values of η = 40 - 41 % as also attained with good diesel engines, were recorded in RPM ranges between 800 and 1,800 RPM/min. (Fig. 23). One can assume an energy consumption of 1 : 1 compared to diesel. There are interesting developments to be observed here, such as e.g. heat reclamation from the cooling water in the Mercedes-Benz M 407 hGO engine (see Fig. 24 (21)).

In practical operations in city bus traffic, however, the driver behaviour of the individual operators had a marked influence on average consumption. Some drivers take advantage of the excellent acceleration characteristics, so that they have to brake and wait at the next set of traffic lights. This means that comparisons with diesel buses are occasionally difficult.

The emission values of the buses used in the FMRT M 100 programme are very favourable and meet the limiting values demanded in the "13 Mode

Test (California 1983)". Worthy of mention is the reduced engine noise compared to diesel buses.

4.3.2. M 100 Commercial Vehicles/Buses - Lubrication and Wear/Customer Acceptance

Unlike the problems with M 100 passenger cars, the lubrication and wear problems with the commercial vehicles/buses could be solved by means of close cooperation between the lubricant manufacturers and engine developers (32). The metal concentrations finally measured in waste oil drawn off from city buses are very similar to the values from comparable diesel vehicles (Table 9). Thus, comparably good engine lives can be expected.

At the start of developments the following problems cropped up:

- emulsion formation when methanol and lubricating oil came into contact, e.g. in the injection pumps;
- high cylinder wear due to aluminium in the fuel that reached the combustion chamber;
- deposits at locations where blow-by gases came into contact with methanol.

It was possible to solve all of these problems satisfactorily because the engine manufacturers and oil suppliers trustingly carried out research into the real causes, employing the most modern methods. Design measures and a different selection of material by both sides led to success (32).

Since the commercial vehicle/buses do not have any "cold operation" such as the passenger cars, the lubrication and wear problems are far easier to solve. They may be deemed solved for all of the M 100 bus engines used in the FMRT programme.

The buses have excellent customer acceptance (32). The vehicles have proven popular with drivers, who appreciate the higher low-speed torque characteristics of the engines which permit faster acceleration in city traffic, and with the public who have commented on lower noise levels in the bus interior and a lack of vibration when the engine is idling.

5. Economic Considerations

It is not possible here to present a comprehensive economic evaluation. It should be pointed out, however, that all of the work conducted within the scope of the FMRT programme was done in the light of cost/benefit aspects. Since the costs, e.g. prices for oils and methanol, depend upon a great many, partly policital and global economic factors, it was only possible to take trends as a guide for development work (34).

Fig. 25 shows the estimates drawn up in autumn of 1982 by Shell with respect to methanol availability and consumption. Here, it becomes quite clear that more methanol will probably be available than required by the market. This will likely push down prices.

Fig. 26 shows that, given methanol availability - primarily cheap imports! - as early as 1984/1985 the methanol pushing on to the market in Germany will no longer be able to be accomodated as "M 2", which is the grade currently permitted. Accordingly, decisions are required! The same picture also shows that, through "M 15", the quantities of methanol pushing on to the market ~ in the year 2000 will not automatically be taken up.

According to Shell's latest estimates, that are also deemed well-founded by other organizations, this point may already be reached by ~ 1990. If so, then solutions > M 15 possibly even M 100 might be necessary.

The results of the FMRT programme have provided politicians and industry with a basis for decisions that will soon have to be made.

6. Summary and Future Outlook

It was shown in a demonstration test with almost 1,000 vehicles driven by normal citizens under all normal operating conditions for three years that the engine manufacturers and the oil industry are technically in a position to implement an M 15 concept in Germany. The decisive factors are the economic questions which will primarily be influenced by fiscal policy and global economic developments (oil prices!).

The M 100 concept is not quite fully developed technically for private motor cars; but, chances of success are good here as well. The M 100 concept for commercial vehicles/buses has been technically so perfected that large-scale demonstration programmes - e.g. involving urban bus traffic in a large city particularly affected by air pollution - can be commenced at any time.

The competition among the companies taking part in the FMRT programme was not restricted. A vast number of different solutions were worked out on individual questions. All of the interesting basic questions were solved quickly and economically.

The technical results can now be employed by politicians to aid them in making decisions. Economic considerations will be the determining factor in these decisions.

A continuation of M 100 developments has been definitely planned for the future, up to the end of 1983. It remains to be seen whether the technical questions will then be solved to such an extent that a "demonstration project M 100 with customers" can be carried through.

The complex questions of reciprocal effects and interrelationships between fuel additives and luboil additives will probably not be clarified in detail by the end of 1983. They could, however, be very important for the economic parameters (engine life, oil-change periods etc.).

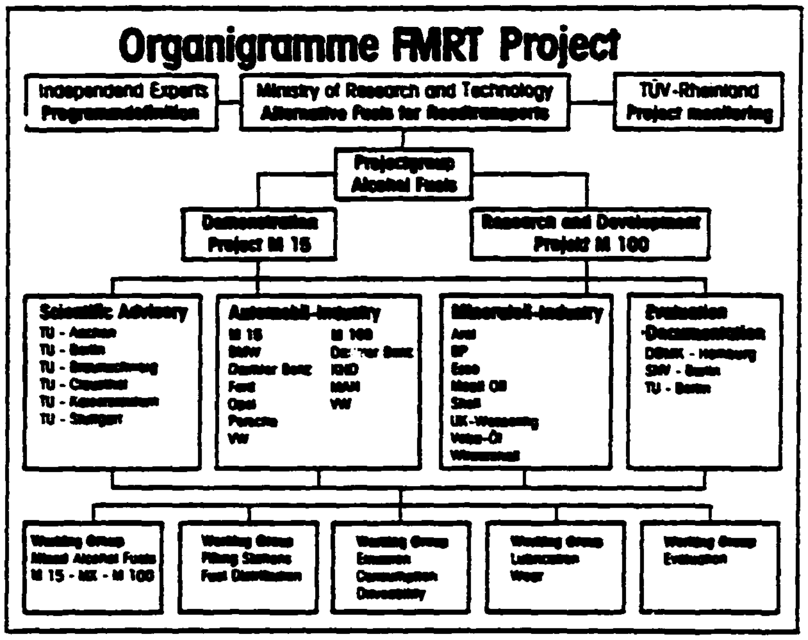

Organigramme FMRT Project
Independend Experts
Programmdefinition
Ministry of Research and Technology
Alternative Fuels for Roadtransports
TÜV-Rheinland
Project monitoring
Projectgroup
Alcohol Fuels
Demonstration
Project M 15
Research and Development
Projekt M 100
Scientific Advisory
TU - Aachen
TU - Berlin
TU - Braunschweig
TU - Clausthal
TU - Kaiserslautern
TU - Stuttgart
Automobil-Industry
M 15
BMW
Daimler Benz
Ford
Opel
Porsche
VW
M 100
Daimler Benz
KHD
MAN
VW
Mineralöl-Industry
Aral
BP
Esso
Mobil Oil
Shell
UK-Wesseling
Veba-Öl
Wintershall
Evaluation
-Documentation
DGMK - Hamburg
SRV - Berlin
TU - Berlin
Working Group
Mixed Alcohol Fuels
M 15 - MX - M 100
Working Group
Filling Stations
Fuel Distribution
Working Group
Emission
Consumption
Driveability
Working Group
Lubrication
Wear
Working Group
Evaluation

Fig. 1 (3)

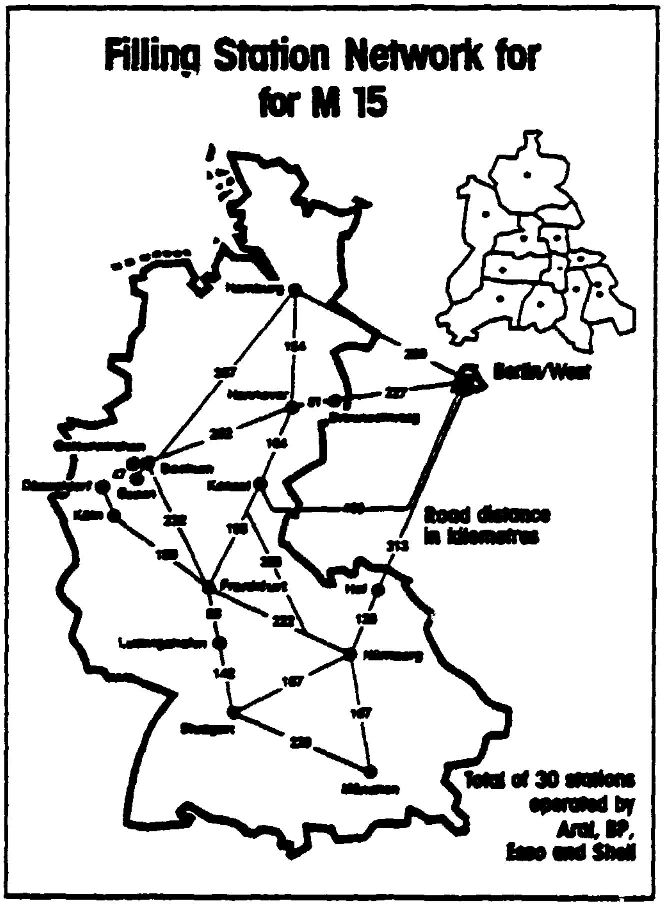

Filling Station Network for
for M 15
Hamburg
Berlin/West
Hannover
Braunschweig
Gelsenkirchen
Bochum
Düsseldorf
Essen
Köln
Kassel
Frankfurt
Hof
Ludwigshafen
Nürnberg
Stuttgart
München
154
287
227
282
164
47
232
198
189
88
222
128
142
167
167
220
313
Road distance
in kilometres
Total of 30 stations
operated by
Aral, BP,
Esso and Shell

Fig. 2 (1)

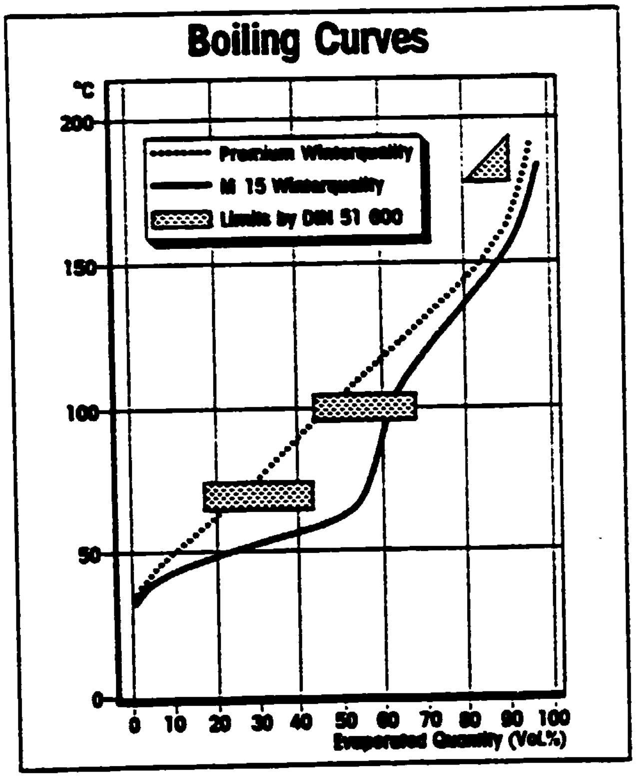

Boiling Curves
°C
200
150
100
50
0
Premium Winterquality
M 15 Winterquality
▨ Limits by DIN 51 600
0
10
20
30
40
50
60
70
80
90
100
Evaporated Quantity (Vol.%)

Fig. 3 (3)

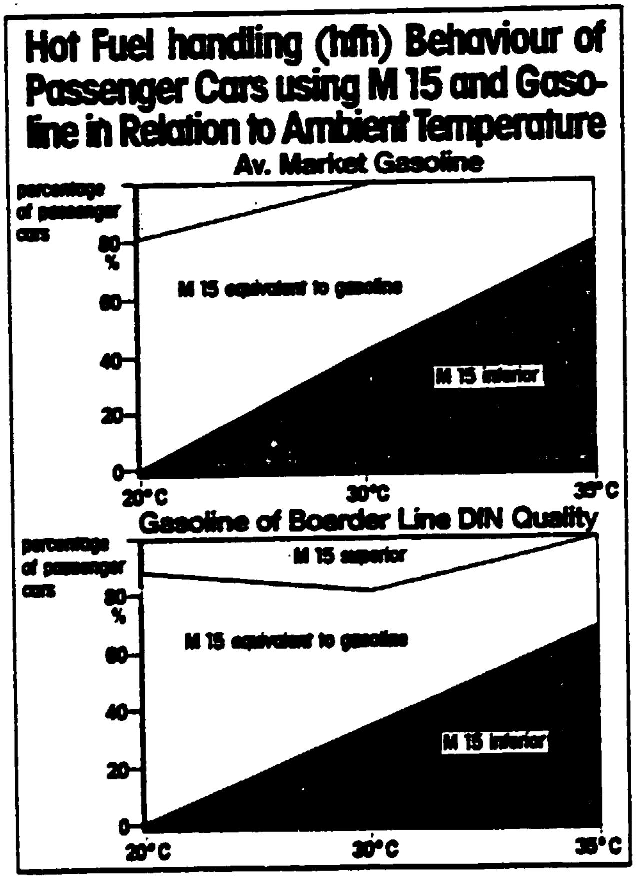

Hot Fuel handling (hfh) Behaviour of Passenger Cars using M 15 and Gasoline in Relation to Ambient Temperature
Av. Market Gasoline
percentage of passenger cars
80
%
60
40
20
0
M 15 equivalent to gasoline
M 15 inferior
20°C
30°C
35°C
Gasoline of Boarder Line DIN Quality
percentage of passenger cars
M 15 superior
80
%
60
40
20
0
M 15 equivalent to gasoline
M 15 inferior
20°C
30°C
35°C

Fig. 4 (5)

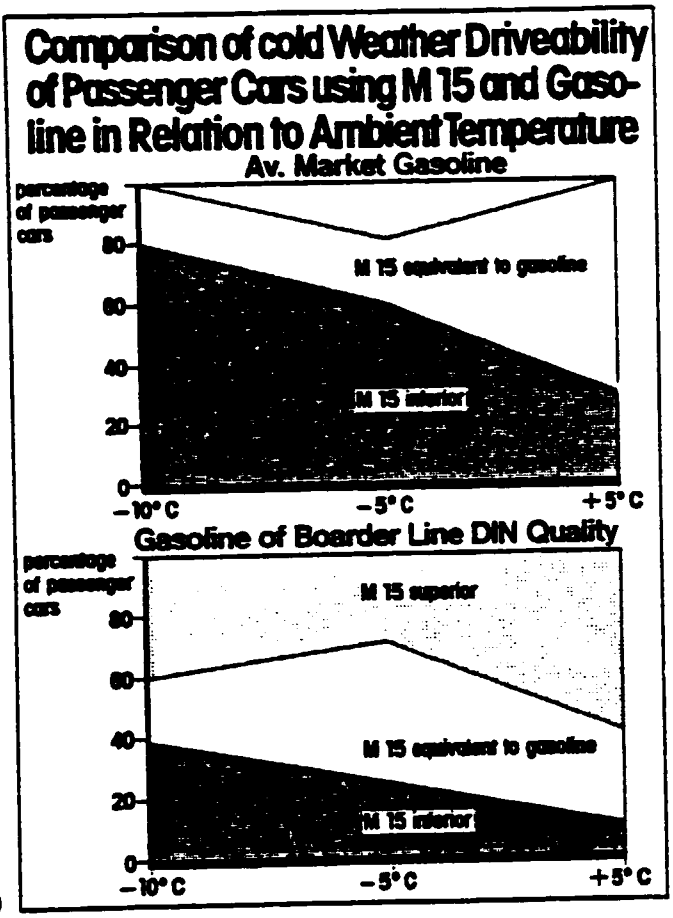
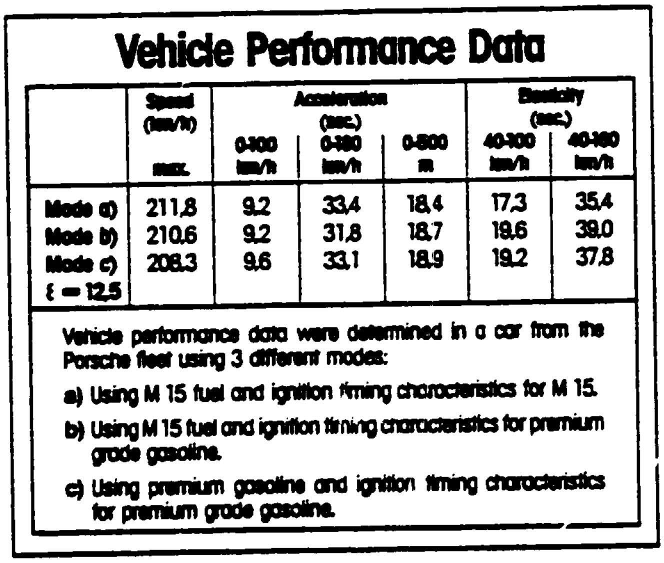


Fig. 5 (5)



Vehicle Performance Data

	Speed (km/h) max.	Acceleration (sec.) 0-100 km/h	0-180 km/h	0-500 m	Elasticity (sec.) 40-100 km/h	40-160 km/h
Mode a)	211,8	9.2	33,4	18,4	17,3	35,4
Mode b)	210.6	9.2	31,8	18.7	19.6	39.0
Mode c)	208.3	9.6	33,1	18.9	19.2	37,8
ε = 12.5						

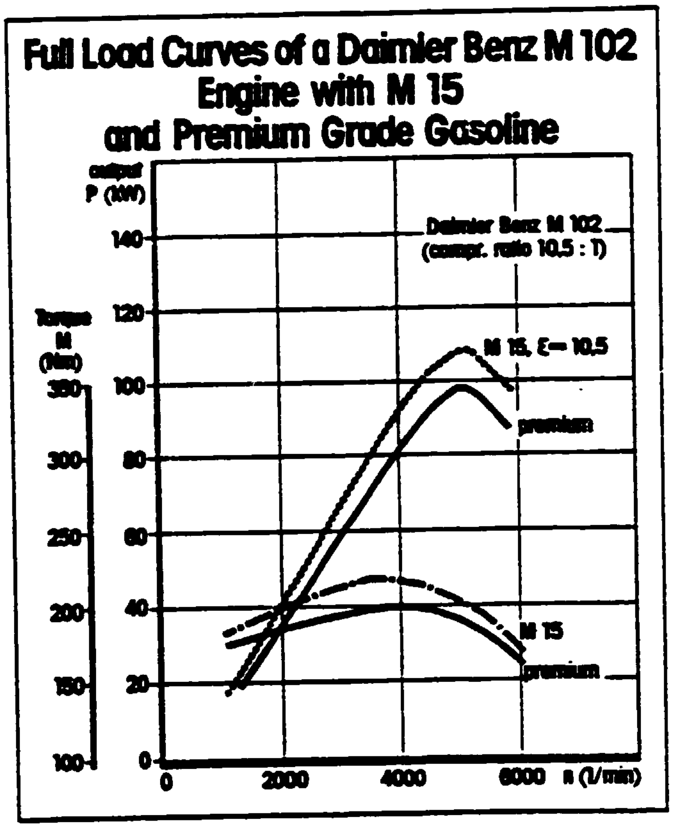
Vehicle performance data were determined in a car from the Porsche fleet using 3 different modes:

a) Using M 15 fuel and ignition timing characteristics for M 15.

b) Using M 15 fuel and ignition timing characteristics for premium grade gasoline.

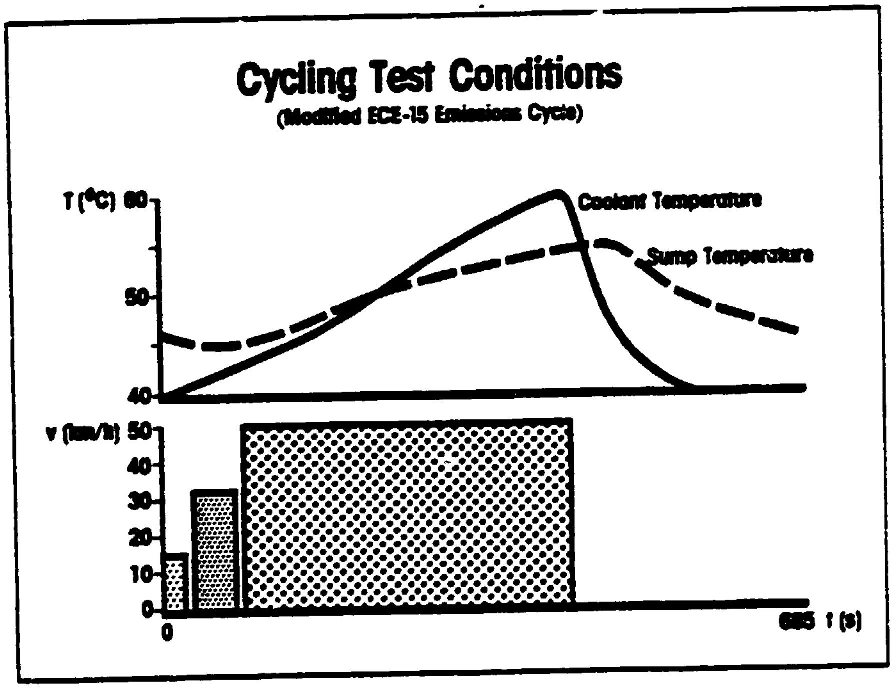
c) Using premium gasoline and ignition timing characteristics for premium grade gasoline.

Fig. 6 (6)



Full Load Curves of a Daimler Benz M 102 Engine with M 15 and Premium Grade Gasoline

Fig. 7 (7)



Cycling Test Conditions
(Modified ECE-15 Emissions Cycle)

Fig. 8 (8)

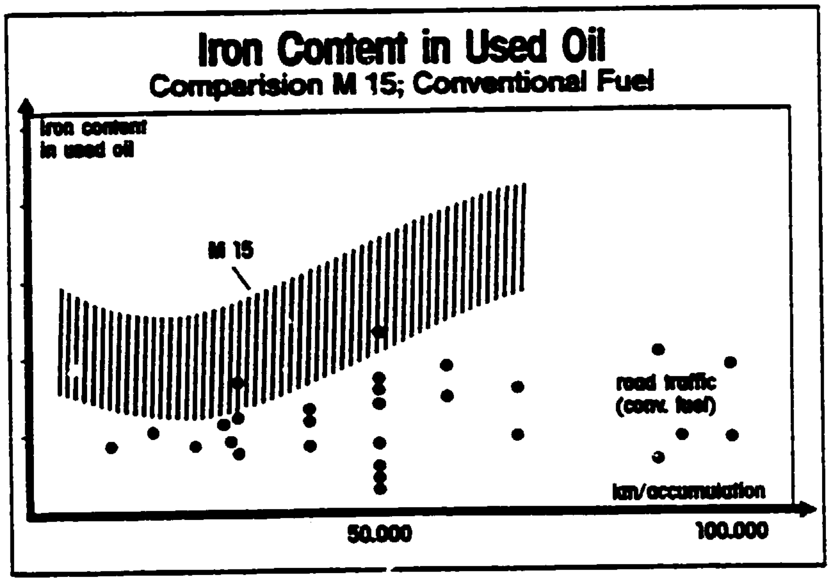


Fig. 9 (9)

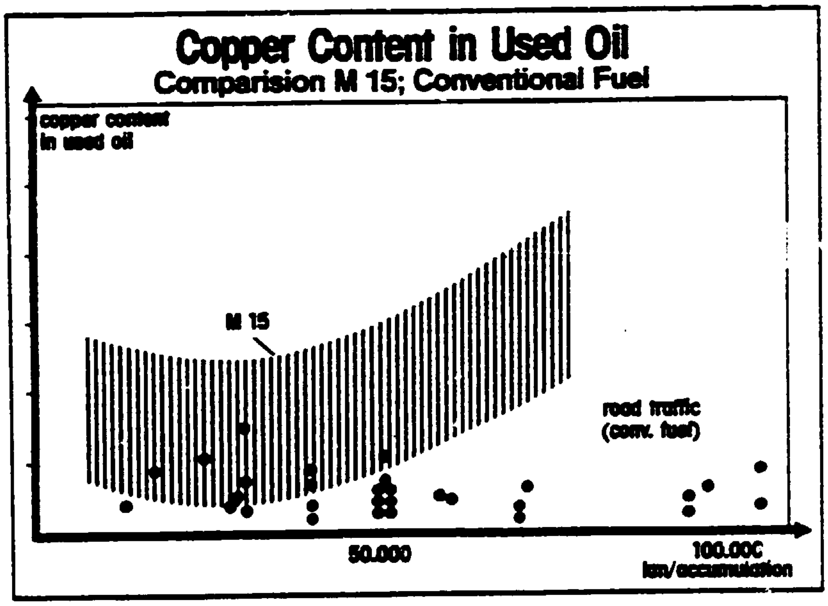


Fig. 10 (9)

Calculation of Fuelconsumption from Measured Emissions

$$M_K = \frac{a \cdot HC + 0{,}429 \cdot CO + 0{,}273 \cdot CO_2}{a}$$

M_K = fuel mass
HC = Hydrocarbon mass
CO = CO mass
CO_2 = CO_2 mass

Numbers of the fuelspecific constant α:

Gasoline : α = 0,866
M 15 : α = 0,792
Methanol: α = 0,375
M 100 Summer : α = 0,398
M 100 Winter : α = 0,411

Fig. 11 (13)

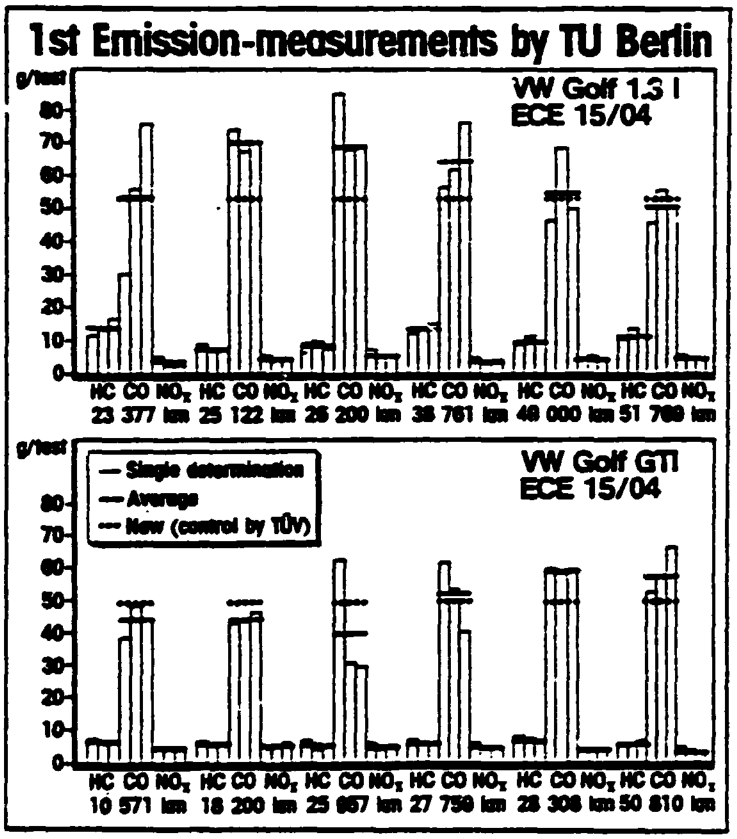

1st Emission-measurements by TU Berlin

Fig. 12 (12)

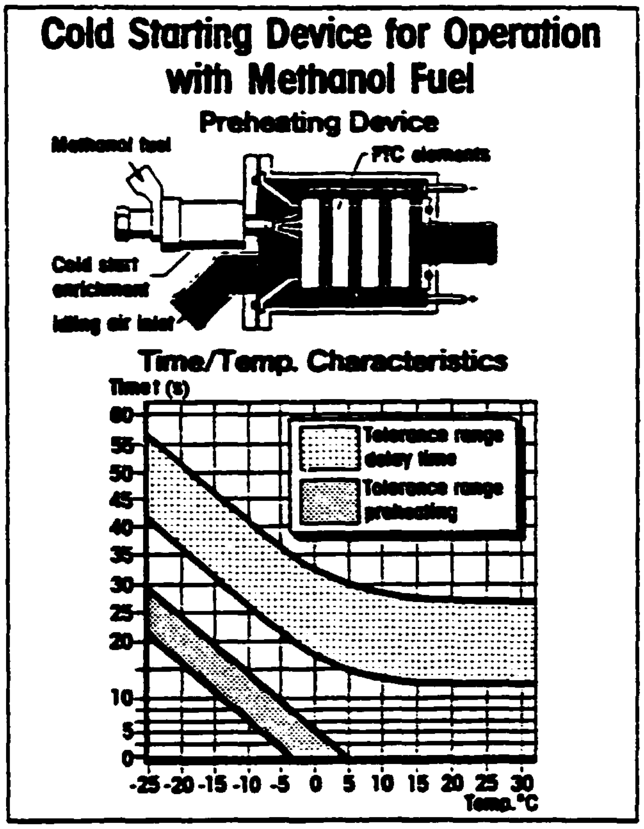


Fig. 13 (15)

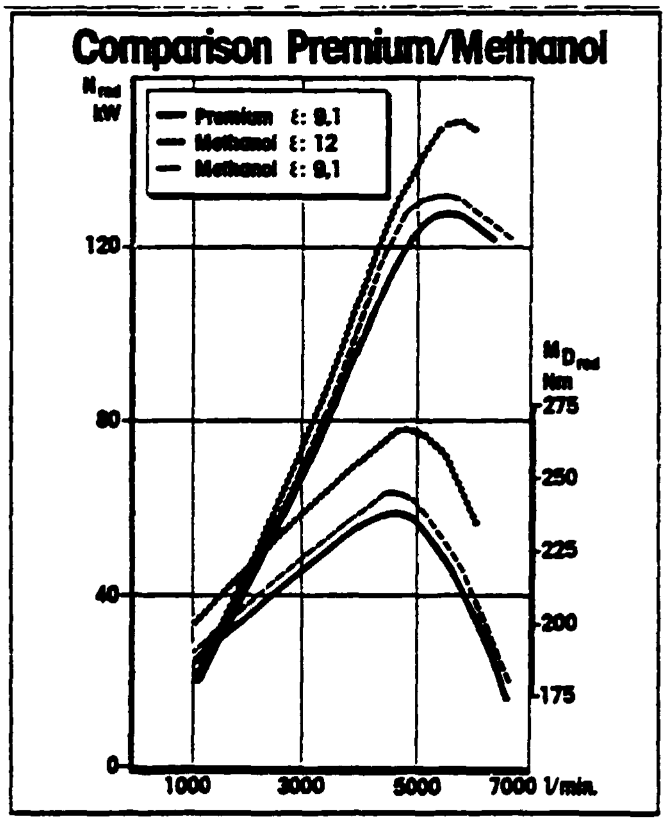


Fig. 14 (15)

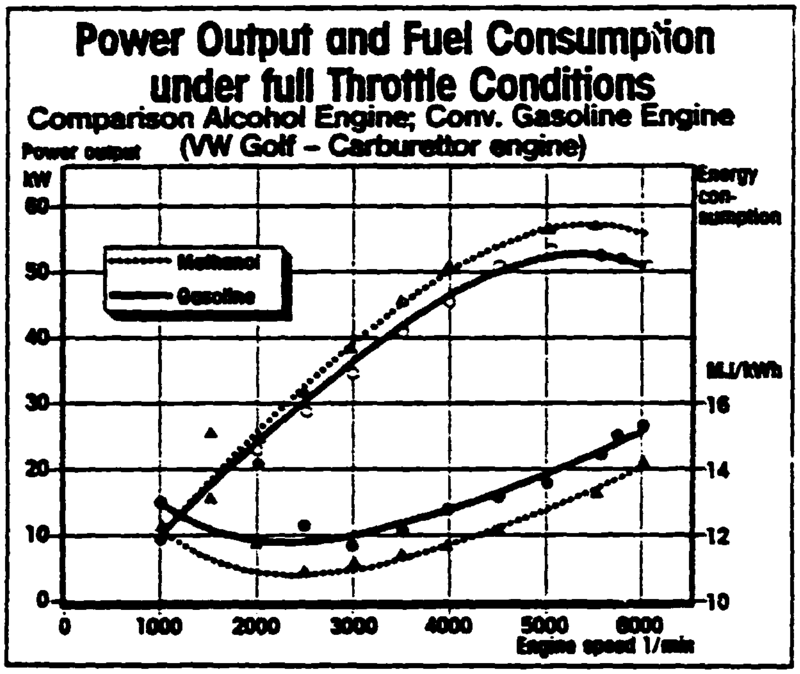


Fig. 15 (16)

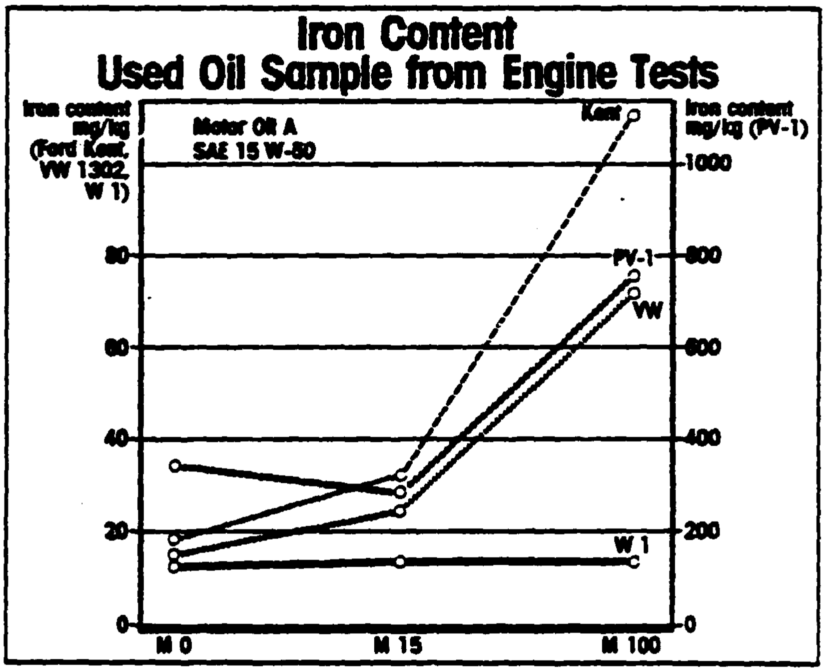


Fig. 16 (18)

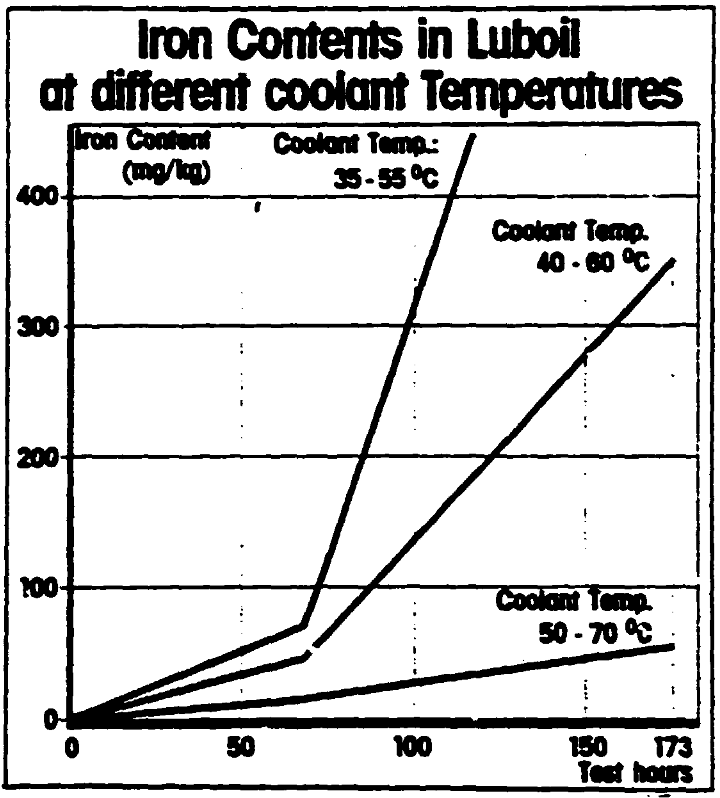


Fig. 17 (30)

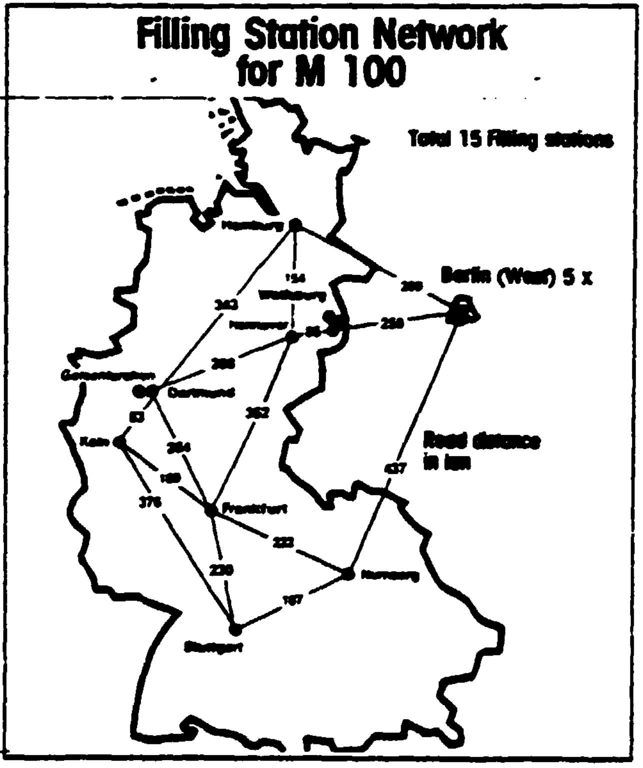


Fig. 18

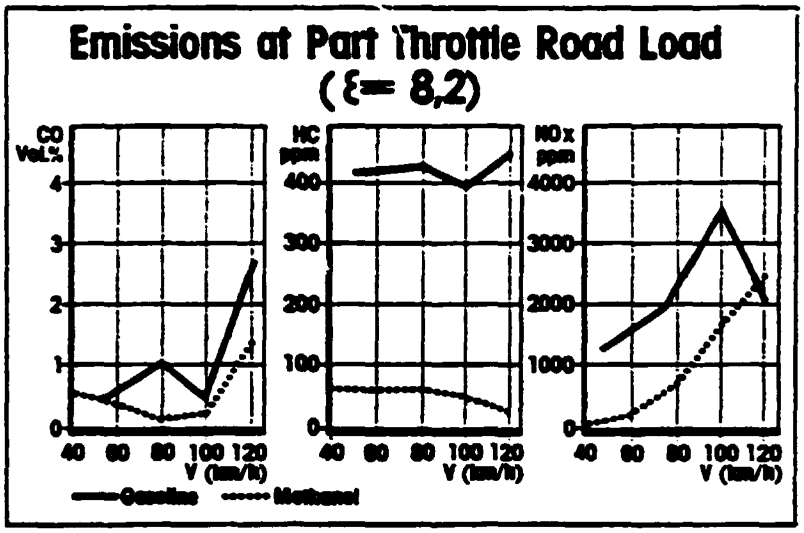


Fig. 19 (16)

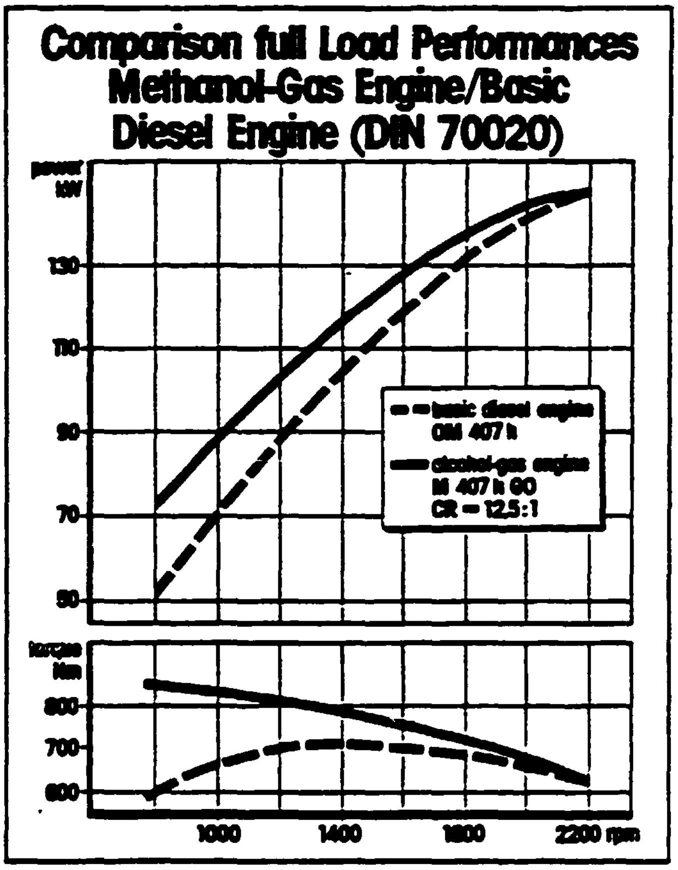


Fig. 20 (21)

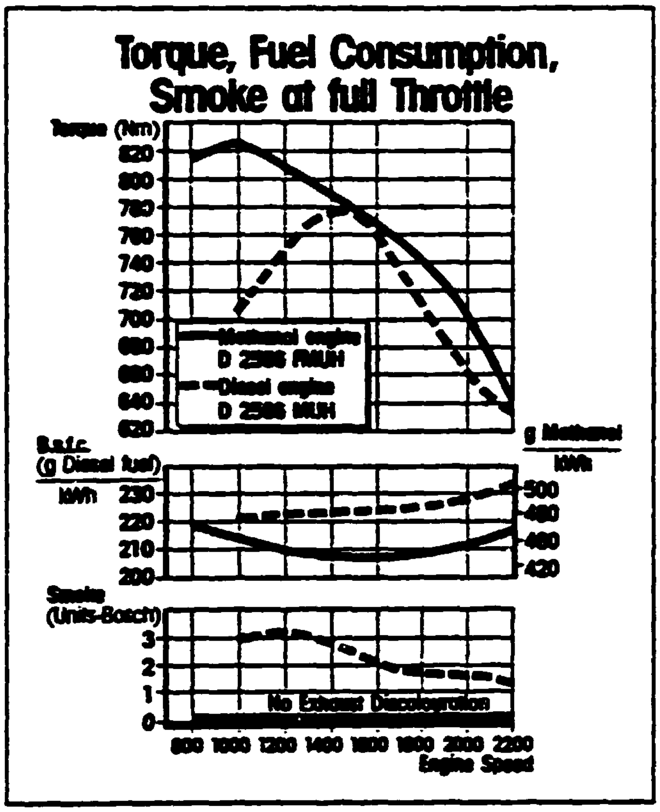


Fig. 21 (24)

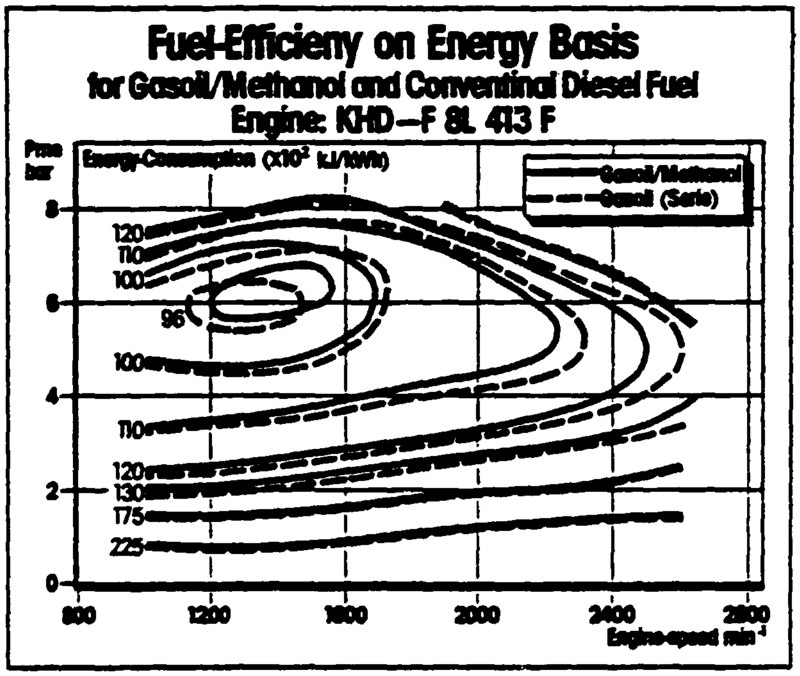
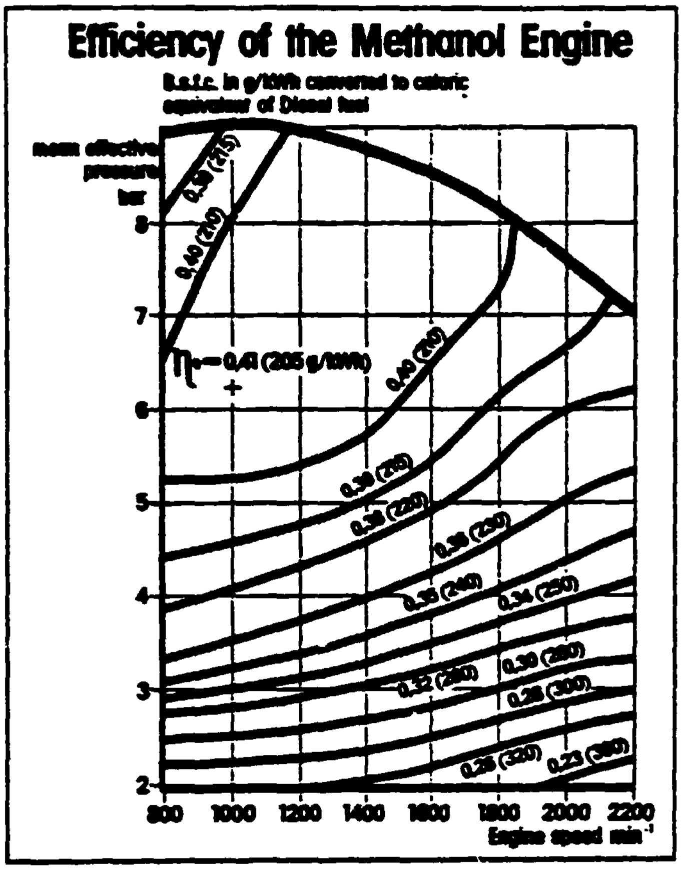
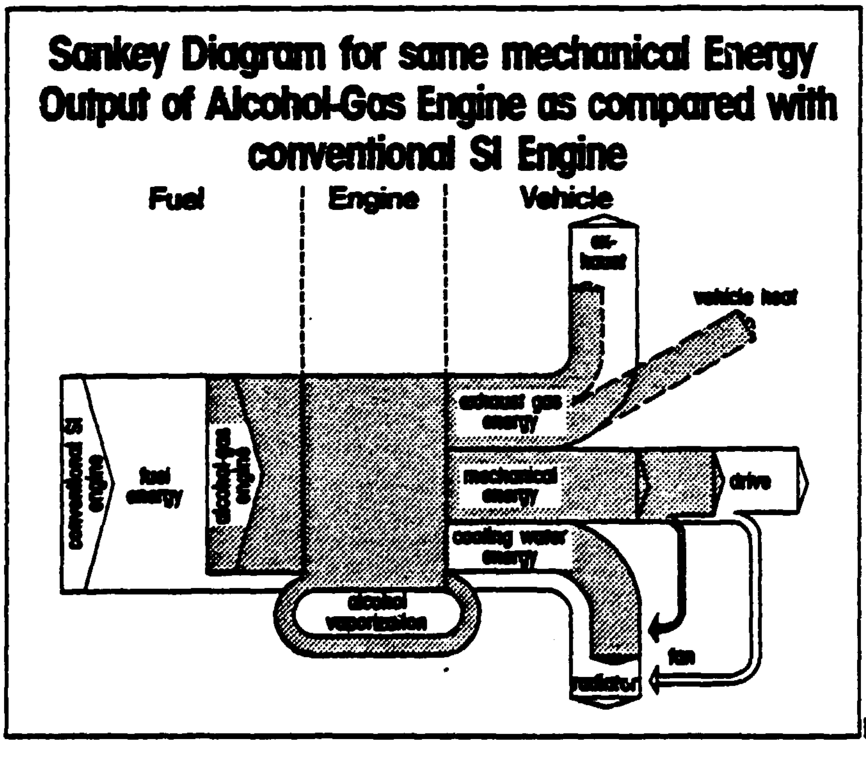


Fig. 22 (25)



Efficiency of the Methanol Engine

Fig. 23 (24)



Sankey Diagram for same mechanical Energy Output of Alcohol-Gas Engine as compared with conventional SI Engine

Fig. 24 (21)

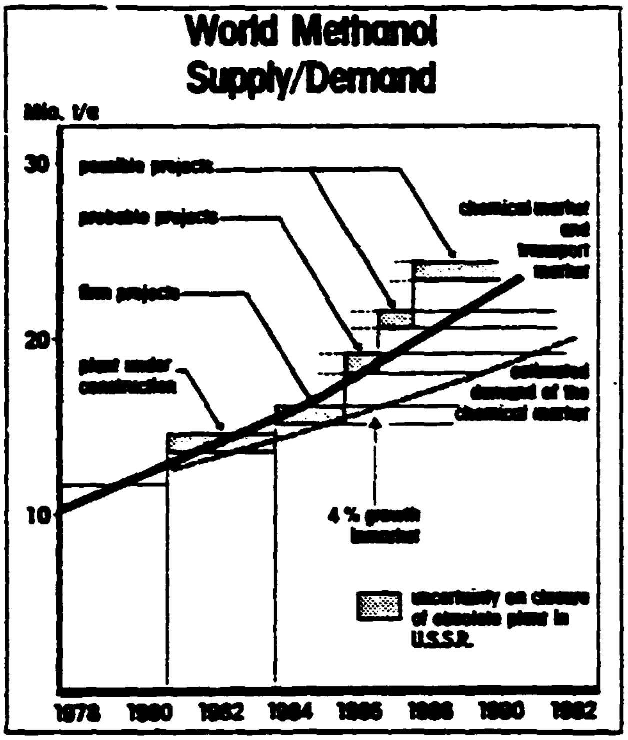


Fig. 25

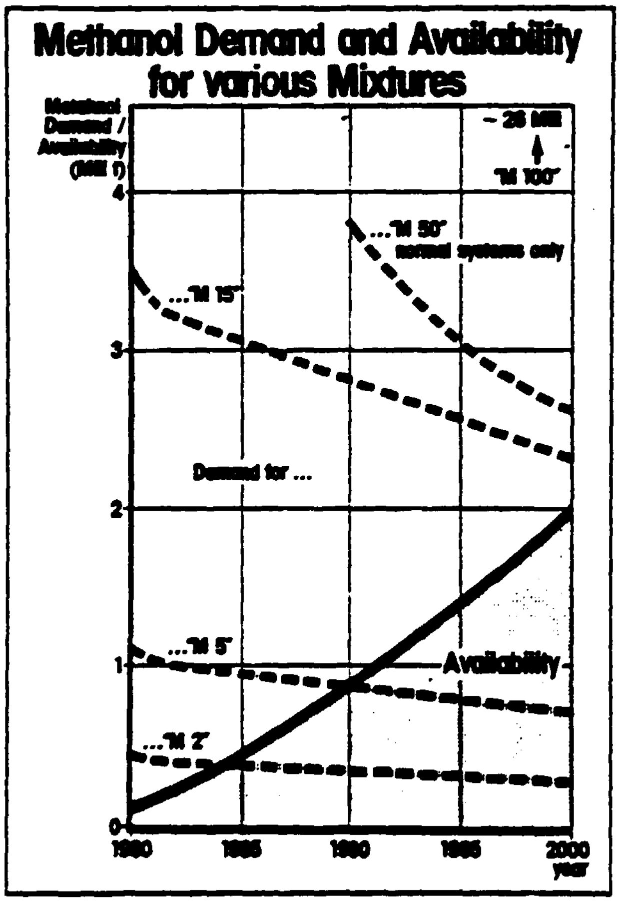


Fig. 26 (34)

M 15 Secification and Actual Results

Test	Dimension	Specification		Actual Results			DIN 51 600 Premium	
		Summer	Winter	Winter '79	Summer '80	Winter '80	Summer	Winter
Methanol Content	% vol	15	15	14,9	14,9	15,5	max 2	
TBA (Solubeliser)	% wt	—	—	1,7	—	0,8	—	
Spec. Gravity (15° C)	g/ml	min. 0,730 max. 0,780	min. 0,730 max. 0,780	0,756	0,774	0,753	min. 0,730 max. 0,780	
RON		98	98	101,0	102,1	101,0	min. 98	
MON		88	88	88,1	88,3	88,6	min. 88	
Lead Content	g/1	0,15	0,15	0,14	0,14	0,14	max. 0,15	
Evaporation Residue	mg/100ml	5	5	2,3	5,3	2,5	max. 5	
Sulfur Content	% wt	0,1	0,1	0,01	0,01	0,01	max. 0,1	
Phase Separation	°C	—	—	-38	-49	-42,5	—	
with water addition (0,15 % Vol—Summer 0,10 % Vol—Winter)	°C	0	-15	-15	-8,5	-19	—	
Reid Vapor Pressure	m bar	800±40	1000±40	950 (wet) 970 (dry)	800 (wet) 880 (dry)	920 (wet) 1010 (dry)	min. 450 max. 700	min. 600 max. 800
Destillation:								
Condensate till 70°C	% Vol	min. 50 max. 55	min. 55 max. 60	57	51	58	min. 15 max. 40	min. 20 max. 45
Condensate till 100°C	% Vol	min. 50 max. 70	min. 55 max. 75	64	56	64	min. 42 max. 65	min. 45 max. 70
Condensate till 180°C	% Vol	min. 90	min. 90	96	94	97	min. 80	min. 90
Final Boiling Point	°C	max. 215	max. 215	205	206	189	max. 215	max. 215
Residue	% Vol	max 2	max. 2	1	1	1	max. 2	max. 2

Table 1 (4)

Specification for Methanol as Mixing Component

Spec. grav.	g/cm^3	ca.	0,79
Reid vapor press.	mbar	ca.	320
Water content	ppm	max.	1000
Evaporation resid.	mg/l	max.	10
Methyl formate	ppm	max.	5
Formic acid	ppm	max.	10
Alkalinity	ppm	max.	1
Total acid	ppm	max.	20

Table 2

Basic-Specification for Methanol Fuel M 100

Methanol	%wt	min.	90
Hydrocarbons	%wt	min.-max.	5,0 - 9,0
Additive (Corrosion Detergent)			yes
Spec. grav./15°C	g/cm³	min.-max.	0,765-0,795
Reid vapor press.	mbar	min.-max.	600 - 700
Cal. value net	MJ/kg	min.-max.	21,0 - 22,0
Water content	ppm	max.	1,000
Evap. solid res.	mg/l	max.	10
Methyl formate	ppm	max.	5
Formic acid	ppm	max.	10
Alkalinity	ppm	max.	1
Total acid	ppm	max.	20
Specials for wintertime:			
Reid vap. press.	mbar	min.-max.	800 - 900
Cloud point at 10% wt H_2O add.	°C	max.	– 15

Table 3

BMFT-Specification for M 100 with C_5-CUT/C_4 based on pure Methanol (October 1982)

	Summer	Winter	
Methanol	93	93	% mass
Mineraloil (total)	7	7	% mass
C_5-Cut	6,5	4,9	% mass
C_4	0,5	2,1	% mass
Density	0,786	0,784	g/cm³
Vapour pressure	700	900	mbar
Calorific value	21,3	21,3	MJ/kg
Upper explosive limit	<– 13	<– 25	°C
Water content	max. 1.000	max. 1.000	ppm
Formic acid	<10	<10	ppm
Existent gum	<10	<10	mg/100 ml

Table 4

Improvement of Exhaust Emission obtained with M 15 as compared to Gasoline

HC 6,7 %
CO 15,5 %
NO_x 5,3 %

Table 6 (14)

Fuel Consumtion Daimler-Benz Typ 280 SE

Test fuels / Test conditions	urban driving conditions ECE		90 km/h		120 km/h	
	l/100 km	MJ/100 km	l/100 km	MJ/100 km	l/100 km	MJ/100 km
Premium	16,8	554	9,4	310	11,7	386
M 100 (ε : 9,1)	30,6	510	18,4	306	22,4	373
M 100 + catalys.	30,6	510	18,4	306	22,4	373
M 100 (ε · 12) opt.	28,6	476	18,2	303	21,4	356
M 100 opt.+catalys.	28,6	476	18,2	303	21,4	356

Table 7 (15)

Comparison of Engine Test Results on Gasoline M 15 and M 100 Fuels

Test	Gasoline	M 15	M 100	Specification
II-D				
Avg. engine rust	8.8	9.0	8.1	8.5 min.
III-D				
Viscosity increase at 64 h. %	54	54	32	375 max.
Piston varnish	9.3	9.4	9.2	9.2 min.
Avg. sludge	9.6	9.8	9.7	9.2 min.
ORLF varnish	7.5	7.5	7.7	4.8 max.
Cam and lifter wear, avg. mils	1.2	1.9	3.1	4 max.
Cam and lifter wear, max. mils	3.7	3.3	6.2*	8 max.
V-D				
Avg. sludge	9.6	9.5	9.3	9.4 min.
Avg. varnish	7.7	6.9	8.7	6.6 min.
Piston varnish	7.2	7.1	8.4	6.7 min.
Cam wear, avg. mils	0.7	0.3	1.2	1 max.
Cam wear, max. mils	0.8	0.4	5.6	2.5 max.
Petter W-1				
Bearing wt loss 36 h. mg	20	28	30	25 max.
Viscosity increase after 36 h measured at 40° C. %	29	37	22.6	80 max
Cortina H. T.				
Piston skirt varnish	8.8	9.3	9.6	8.7 min.
Avg. ring sticking	10.0	10.0	10.0	9.8 min.
Min. ring sticking	10.0	9.9	9.9	9.0 min.
Volvo B 20				
Total wear, µm cams	30	24		150 max.
tappets	72	94		150 max.
Total pitting, cams	0	0		10 max.
tappets	5.5	2		10 max.

* failing result due to excessive camshaft [illegible]

Table 8 (17)

Aldehyde Emission at Standard Idle Adjustment with and without Catalysts

All Vehicles: Type Golf 1,6 l four Cylinder Engine, Mileage ~20.000 km

Vehicle	Mixture Preparation		Performance	Fuel	Without Catalyst		Precious Metal Oxidation Catalyst		US Standard Catalyst	
			kW/RPM		cold g/test	warm	cold g/test	warm	cold g/test	warm
A	Carburetor	12.5	63/5600	M 100 S	1,107	0,703				
B	Carburetor	12.5	63/5600	M 100 S			0,768	0,104		
C	Carburetor	12.5	63/5600	M 100 S			0,766	0,148		
D	K-Jetronic	12.5	81/6100	M 100 S	0,984	0,694	0,423	0,108	0,363	0,068
E	K-Jetronic	12.5	81/6100	M 100 S			0,512	0,252		
F	Carburetor	12.5	63/5600	Ethan... + 5% H_2O + 1,2 MEK	2,432	0,806			2,748	0,044
G	K-Jetronic	9.5	81/6100	Premium DIN 51 600	0,243	0,232				
H	1,3 l Carburetor	8.3	44/5600	Regular DIN 51 600	0,241	0,204				
H	1,3 l Carburetor	8.3	44/5600	Mixed Fuels M 15	0,315	0,224				

Table 9 (28)

Engine Oil Analysis

Engine: A – Public Transport FRG

	Oil mileage km	Viscosity oil 100°C mm²/s	Metal Contents mg/kg								TBN (HCLO$_4$) mg KOH/g
			Cr	Mo	Al	Fe	Cu	Si	Sn	Pb	
Berlin: Methanol	5.214	13.1	1	5	1	13	20	5	5	8	11.0
Engineoil: Commerc.	9.965	12.8	2	9	3	27	22	7	5	10	9.8
15 W-40 SE/CD	19.743	12.6	2	16	5	62	21	8	5	14	
Pinneberg: Diesel	11.000	13.9	1	5	1	27	5	2	5	6	9.8
Engineoil: as in Berlin	30.000	15.2	1	5	5	73	20	5	5	12	8.8

Table 10

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APPENDIX 2

2 Lecture, dated 04/02/85

LUBRICATION OF M 100 - ENGINES

Results of large scale field trials in West Germany

1. Basic considerations

1.1 Although methanol engines are basically conventional internal combustion engines adapted to the characteristics of methanol fuel, there are significant differences in the combustion process. Each molecule of fuel already contains an atom of oxygen which alters the rate of combustion and causes changes in the intermediate combustion products. The composition of the blow-by gas is modified, and this in turn modifies the demand on the lubricant.

1.2 The engine design has a significant effect on the oil requirements. There is a wide variety of different designs.

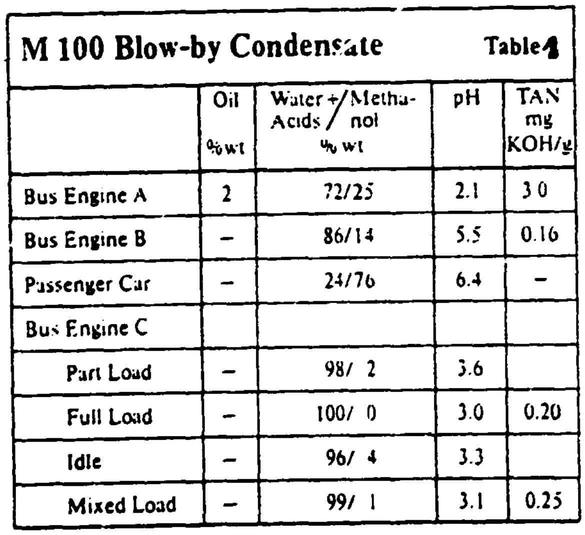
1.2.1 Daimler Benz commercial vehicles- Methanol is passed through a "vaporiser" which draws its energy from engine waste heat prior to mixing with air and subsequent entry into the combustion chamber. Ignition is effected using spark plugs. The compression ratio is 12.5:1.

1.2.2 Klöckner-Humboldt-Deutz (KHD)- Combustion is based upon the diesel cycle with methanol and diesel fuel injected simultaneously into the compressed air charge. The diesel fuel provides the ignition source and the methanol injection rate is varied to provide increases in engine output. MWM and Volvo methanol engines operate on very similar principles.

1.2.3 <u>M.A.N.</u> - Methanol is injected onto the wall of the combustion chamber and ignition is by means of a spark plug. An important feature of this engine is the hemispherical combustion chamber in the piston crown. Compression ratio is 16:1.

1.2.4 Passenger car methanol engines are all Otto-cycle engines, i.e. they have spark ignition.

1.3 To make use of chemical laboratory tests for pre-screening blow-by condensates from methanol engines are useful. Our lubricant development was undertaken in close co-operation with engine manufacturers, who provided us with samples of blow-by condensates from test bed methanol engines. Chemical analysis of these samples showed widely varying results: (see table 1).



M 100 Blow-by Condensate **Table 1**

	Oil %wt	Water + Acids / Methanol %wt	pH	TAN mg KOH/g
Bus Engine A	2	72/25	2.1	3.0
Bus Engine B	–	86/14	5.5	0.16
Passenger Car	–	24/76	6.4	–
Bus Engine C				
Part Load	–	98/ 2	3.6	
Full Load	–	100/ 0	3.0	0.20
Idle	–	96/ 4	3.3	
Mixed Load	–	99/ 1	3.1	0.25

1.4 To establish whether these differences resulted from the different fuel mixing techniques and combustion processes - as we had deduced from theoretical considerations - a blow-by condensation rig was developed (See Fig.1).

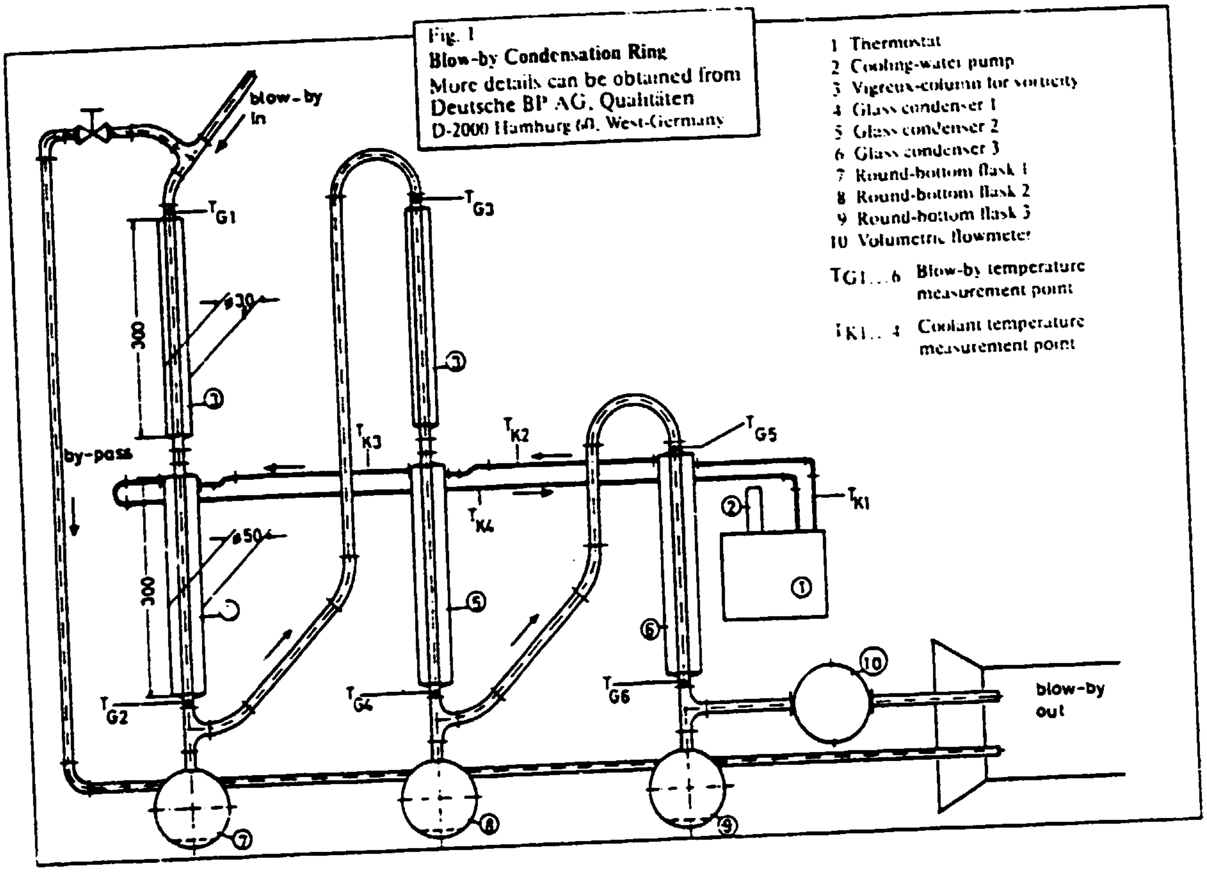


Fig. 1
Blow-by Condensation Ring
More details can be obtained from
Deutsche BP AG, Qualitäten
D-2000 Hamburg 60, West-Germany

The objective was to draw the blow-by gas at high temperature from the engine so as to obtain <u>all</u> condensate components for examination. The rig is constructed using standard glas components and can be produced at low cost. Cleaning is simple and spare parts are readily obtainable.

1.5 The "emulsion formation" sometimes observed in methanol engines, which can occur when the engine oil is contaminated by methanol, can effect the base oil components (mineral or synthetic) and the additives used. These reactions can be evaluated in simple laboratory screening tests. We have found that these "emulsions" can be removed simply by heating to about 90°C. The methanol is then evaporated and fed back to the engine intake system. Engine manufacturers have meanwhile patented such systems. In the locations where emulsions occur it is possible that as a result of viscosity changes the "mechanical" lubricating characteristics, i.e. the formation of a hydrodynamic wedge, could be affected.

1.6 The examination of used oil samples produced particularly important results. Additive depletion and increased wear element contents were observed in some cases.

Engine Oil Analysis Table 2

Engine: A
Part and Full Load Bench Test

Engine Oil:
1. Commercial 20W-20 SE/CC
2. Experimental 15W-40 SE/CC

Test Duration hrs	Viscosity at 100°C mm²/s	Metal Contents: mg/kg								IR		Methanol mg/kg	TBN (HClO4) mg KOH/g	Acid Value mg KOH/g
		Cr	Mo	Al	Fe	Cu	Si	Sn	Pb	ZDDP Depletion	Base Oil Oxidation			
1. 0	9.2												6.6	2.7
150	8.9	5	11	46	56	150	11	6	14				2.3	4.6
200	9.0	6	15	50	88	180	15	9	17	100	0.2	180	<1.5	5.2
2. 0	14.8												7.2	3.4
50	13.6	<1	< 5	< 1	28	11	< 1	<5	< 5				3.9	3.9
100	13.1	1	< 5	< 1	120	390	2	5	5				2.6	4.8
200	13.2	4	12	6	220	460	6	8	14	87	0.1	160	<1.5	6.5

Table 2 shows the results of 200 hr full load bench tests on bus engine A. In both cases alarming used oil data correlated with unsatisfactory engine inspection results, e.g. corroded cylinder liners and heavily worn main bearings. An extensive search in our own laboratories by using electron microscopic on the surfaces finally revealed that a chlorine contamination of the methanol had corroded the liner and piston material and the resulting wear particles had damaged the bearings. Table 3 shows the laboratory methods used for examining the used oil samples

Laboratory Methods:

Viscosity – Ubbelohde capillary
Metal contents – Spark emission spectroscopy
ZDDP depletion – IR absorption at 1000 cm⁻¹
Base oil oxidation – IR absorption at 1700 cm⁻¹
Methanol content – Gas chromatography
TBN ($HClO_4$) – ASTM D 2896
Acid Value – TMAH titration DIN draft
TAN – ASTM D 974

Engine Oil Analysis Table 4

Engine: A, 53 hrs Bench Test

Engine Oil: Commercial SAE 30 API CC

Test Duration hrs	Viscosity at 100°C mm²/s	Metal Contents: mg/kg								IR		Methanol mg/kg	TBN ($HClO_4$) mg KOH/g	Acid Value mg KOH/g
		Cr	Mo	Al	Fe	Cu	Si	Sn	Pb	ZDDP Depletion	Base Oil Oxidation			
0	12.1												6.0	
10	11.7	< 1		< 1	10	11	2	<5	< 5	23			5.4	
20	11.3	< 1		< 1	12	17	3	<5	< 5	35			4.7	
31	11.4	< 1		5	430	10	12	<5	< 5	46			4.2	
40	11.3	4		14	450	80	12	<5	18	68			3.2	
53	11.5	12		86	500	100	15	<5	21	79	0.1	180	2.9	

1-7 Table 4 shows results of an oil evaluation following a test bed run, in which high aluminium and iron contents were recorded unexpectedly. The condition of this engine in terms of wear was most unusual. The cylinder showed very high "barrelling" wear, i.e. in contrast to the usual wear pattern considerable loss of material had occurred in the areas swept by the piston at high speed. As hydrodynamic lubrication should take place in these areas it was suspected that abrasive mechanical wear had occurred. Scanning electron microscope photographs (see Fig.2) showed deep scoring marks at the end of which all ventitious material was discovered. It was identified as aluminium oxide in the microprobe.

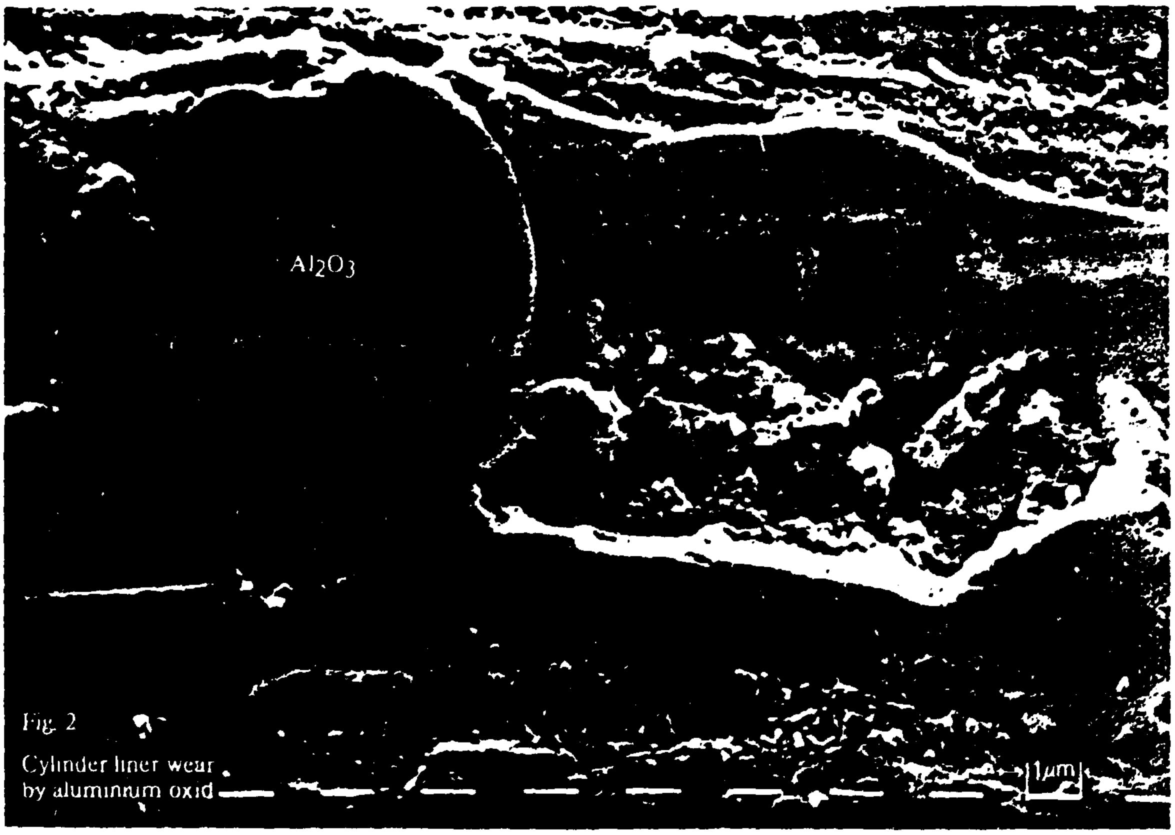


Fig. 2
Cylinder liner wear
by aluminium oxid

It was learned in discussions with the engine manufacturer that methanol could have come into contact with hot aluminium components in the fuel system. This had probably led to the formation of aluminium methylate, which was converted to aluminium oxide in the combustion chamber. This is a "grinding paste" and it is impossible to counteract its effects with any lubricant.

The aluminium components were manufactured from other materials subsequently and the wear pattern in this engine returned to normal.

1.8 Table 5 shows results of a 100 hr test bed run in which a relatively low iron content was observed in the lubricant. On stripping the engine a thin brown layer of deposit was found on the upper third of the cylinder swept surface. It is possible that the deposit had protected the area near t.d.c. where relatively high wear usually occurs as a result of boundary lubrication condition due to the reversal in the direction of travel of the piston.

Engine Oil Analysis Table 5

Engine: Bus Engine B,
Full Load Bench Test

Engine Oil:
Experimental 15W-40 SF/CC

Test Duration hrs	Viscosity at 100°C mm²/s	Metal Contents: mg/kg								IR		Methanol mg/kg	TBN (HClO4) mg KOH/g	Acid Value mg KOH/g
		Cr	Mo	Al	Fe	Cu	Si	Sn	Pb	ZDDP Depletion	Base Oil Oxidation			
0	14.8												7.0	3.2
25	13.9	2	<5	4	9	2	<1	<5	6	4	0.2	<100	6.7	2.5
44	13.9	3	<5	5	12	2	<1	<5	7	4	0.2	<100	6.7	3.6
75	14.9	5	<5	7	52	11	<1	8	12	13	0.3	<100	5.8	4.9
100	15.2	7	<5	8	60	15	<1	9	14	17	0.3	<100	5.3	6.3

The formation of layers of deposit, which apparently originate mainly from reactions of methanol and blow-by gases with engine oil vapour, can be counteracted either via oil formulation or by use of fuel additives.

Preliminary results indicate, however, that the quantity of fuel additives must be approximately trebled. As methanol has only about half the calorific value of gasoline, roughly six times the quantity of fuel additive would have to pass through the engine in comparison with a conventional gasoline engine. Apart from the cost involved this raised the question of the effect on the lubricant of the increased quantity of fuel additive reaching the crankcase.

1.9 The corrosive effect of methanol on some aluminium alloys has been mentioned already under 1.7. In addition, it is known that other metals, e.g. copper, tin react with impurities in the methanol particularly at higher temperatures. Copper compounds which reach the engine oil can accelerate the base oil aging process. Suitable oil additives can be used to counteract this effect by catching the copper ions. Nevertheless, it is important in the construction of the engine and fuel system to use if possible only those materials which do not react with methanol.

1.10 At this point it should be emphasised that "methanol" can be a misleading term if it is not specified fully.

Corrosion problems can be caused in certain circumstances by impurities already present in the fuel (acids, ketones, aldehydes). The quantity of these impurities varies considerably with the source of the methanol. In this situation the contribution which the lubricant can make is limited.

To correct this situation an initiative has been started in West-Germany (FRG) and USA to propose a standard for "M 100 motor fuel". As to now (spring 1985) the proposal calls for:

85% (vol) AA grade Methanol, with
  max 2 ppm chlorine
  max 5 ppm methyl formate
  max 10 ppm formic acid
  max 20 ppm total acid

\+ 15 % (vol) unleaded gasoline, containing
  min 40% aromatic components.

This type of hydrocarbon content is needed to give a visible flame even under strong winds if the "M 100 Motor fuel" is burning accidentally. It also compresses the danger of an explosive gas mixture above the liquid level in the fuel tank.

---

2. Results in Commercial Vehicles

2.1 At the start of development the following problems cropped up:

- emulsion formation when methanol and lubricating oil came into contact, e.g. in the injection pumps.

This problem was overcome by changes in the construction (see 1.5).

- high cylinder liner wear due to aluminium in the fuel that reached the combustion chamber.
  This problem was overcome by better house-keeping and changes in material (see 1.7).
- deposits at locations where blow-by gases came into contact with methanol.
  This problem was overcome in commercial engines by changes in design. It is still a problem in passenger car engines, in which we are trying to solve the difficulties by improved base oil qualities giving less oil fumes. Finally some changes in the engine design will probably be necessary.

2.2 Commercial Engine Oil SAE 15W-40 SE/CD and an Experimental Engine Oil SAE 15W-40 SF/CC were evaluated side by side. Both oils gave finally very satisfactory results.

Engine Oil Analysis

Engine: A - Public Transport FRG

	Oil mileage km	Viscosity at 100°C mm²/s	Metal Contents mg/kg								TBN (HClO₄) mg KOH/g
			Cr	Mo	Al	Fe	Cu	Si	Sn	Pb	
Berlin: Methanol	5.214	13.1	1	5	1	13	20	5	5	8	11.0
Engineoil: Commerc.	9.965	12.8	2	9	3	27	22	7	5	10	9.8
15 W-40 SE/CD	19.743	12.6	2	16	5	62	21	8	5	14	
Pinneberg: Diesel	11 000	13.9	1	5	1	27	5	2	5	6	9.8
Engineoil: as in Berlin	30.000	15.2	1	5	5	73	20	5	5	12	8.8

Table. 6

Table 6 shows that the wear elements in methanol engine used oil samples even after 20.000 Km. without oil change were very similar to those from diesel engines of comparable desig using the same oil.

2.3 German engine manufacturers of methanol commercial engines (Daimler-Benz, KHD, MAN) are now recommending for their engines well tested high quality commercial oils by name, because they have done long duration road tests in practical service with these oils.

It is not adequate to give certain typical analytical data like TBN, ash content etc. for these oils. The decrease in TBN, for example can be rather different over the running time depending on the total composition of the additive package.

The principal trends, however, can be described as follows:

- Base oil of high quality in order to obtain a multigrade oil with comparatively low amount of VI-Improver.
- Additive package as for long oil drain periods in diesel engines.
- TBN in the order of 10 to 12.
- Ash content below 1.5 % wt.

3. Results in Passenger Cars

3.1 A test fleet of about 100 vehicles was run over 3 years. Several cars did more than 150.000 Km. each during this time. 3 different types of engines were used as shown in table 7.

M 100 ENGINES OF PASSENGER CARS

M 100 Motoren der Pkw-Flotte

Nr.	1 Carburettor Vergaser	2 Injection Einspritzer	3 Injection Einspritzer
Swept Volume **Hubraum**	1,6 l	1,6 l	2,8 l
Leistung Power	63 kW 4 Zyl.	81 kW 4 Zyl.	136 kW 6 Zyl.
Verdichtung Compression	12,5	12,5	9,0
Number of Cars under Used Oil Control **Anzahl Fahrzeuge in der Ölüberwachung**	36	10	8

Table 7.

3.2 Two principal problems became obvious.

- heavy deposit build up in the inlet system causing trouble on the throttle plate and the jets in the carburettor as well as on the nozzels of the injection engines.
- Corrosion and wear in engines which were operated with low temperatures in the cooling system.

3.2.1. The sticky deposits caused most serious troubles in the injection engines because they influenced the combustion by blocking partly the injection nozzels.

In carburettor engines conventional multigrade oil SAE-15W-40 SF/CC produced during 40.000 Km. running a black layer of several millimeter thickness. The ideling jet and the adjustment screw had to be cleaned several times during this run.

Analysisg these deposits it was found that high molecular weight substances like those used in VI-improver or dispersants were present. These substances are not soluble in methanol and are obviously precipitated by methanol droplets or even methanol vapor. Soot and dust are collected on the sticky surface and form finally the black paste. This process took place where blow-by gases came in contact with the intake air containing methanol.

To overcome the difficulty single grade oils SF/CC were tryed but the success was only marginal.

Three principle approaches via oil formulations are possible:

- synthetic base stocks which would not require VI improver to formulate a multigrade oil. These base stocks have very low evaporation losses and thus the blow-by gases are more or less free of "oily components". This approach seems to be the best, but it is very expensive and could discriminate the methanol engine.

- hydrogenated base stocks which would have a VI of approx. 120 and thus require only very little VI improver to formulate a multigrade oil. These base stocks are developed during the last few years and the normal additives have a different response in these basestocks. Therefore, further development to detect synergistic and antagonistic effects has to be performed. Basically this approach looks promising.
- the "classical" approach is using high quality but normal basestocks. It is tried to overcome the shortcomings like deposit formation and wear by using special additive combinations. The results have not been convincing upto now.

3.2.2 The increase in corrosion and wear by using M 100 fuel is indicated in Fig.2.

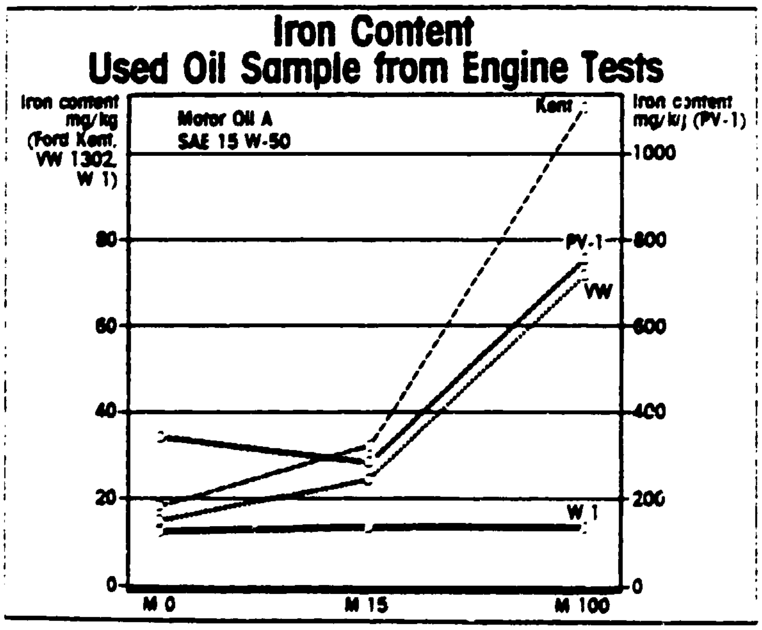
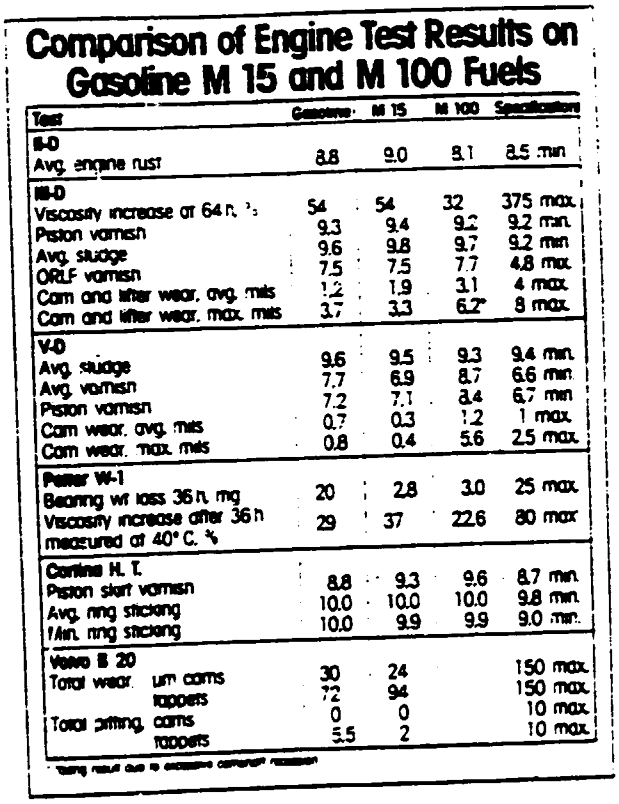


Fig. 2

The Petter W1 high temperature test did not provide any results that would indicate problems with M 100.

The cortina high temperature test with M 100 gave an excellent result in terms of piston cleanliness and ring sticking (see table 8), but heavy black deposits were found in the inlet system.



Comparison of Engine Test Results on Gasoline M 15 and M 100 Fuels

Test	Gasoline	M 15	M 100	Specification
II-D				
Avg. engine rust	8.8	9.0	8.1	8.5 min
III-D				
Viscosity increase at 64 h, %	54	54	32	375 max.
Piston varnish	9.3	9.4	9.2	9.2 min.
Avg. sludge	9.6	9.8	9.7	9.2 min
ORLF varnish	7.5	7.5	7.7	4.8 max
Cam and lifter wear, avg. mils	1.2	1.9	3.1	4 max
Cam and lifter wear, max. mils	3.7	3.3	6.2*	8 max.
V-D				
Avg. sludge	9.6	9.5	9.3	9.4 min.
Avg. varnish	7.7	6.9	8.7	6.6 min.
Piston varnish	7.2	7.1	8.4	6.7 min
Cam wear, avg. mils	0.7	0.3	1.2	1 max.
Cam wear, max. mils	0.8	0.4	5.6	2.5 max.
Petter W-1				
Bearing wt loss 36 h, mg	20	28	30	25 max.
Viscosity increase after 36 h measured at 40° C, %	29	37	22.6	80 max
Cortina H. T.				
Piston skirt varnish	8.8	9.3	9.6	8.7 min.
Avg. ring sticking	10.0	10.0	10.0	9.8 min.
Min. ring sticking	10.0	9.9	9.9	9.0 min.
Volvo B 20				
Total wear, µm cams	30	24		150 max.
tappets	72	94		150 max.
Total pitting, cams	0	0		10 max.
tappets	5.5	2		10 max.

* [illegible]

Table 8

In the VW 1302 test, too piston cleanliness is better with M 100 than with the reference fuel, but the iron content (see Fig.2) in the used oil is approx. 5 times as high with M 100. To study the wear problems in standard engines the "city driving programme" (see Fig.3), as known from the M 15 experiments, was varied with respect to coolant operating temperatures.

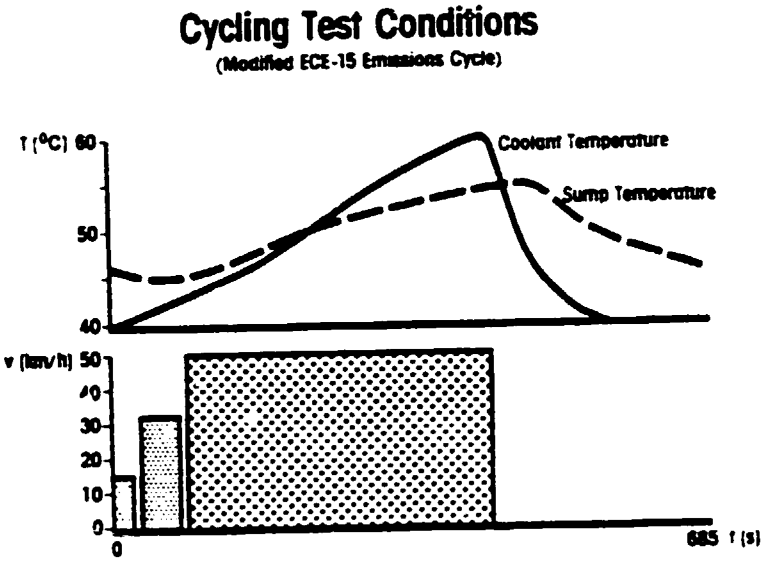


Fig. 3

Fig. 4 shows that there is no kink in the wear curve into the "high wear range" at coolant temperatures of between 50 and 70°C.- normal ∼ 50 mg Fe/kg oil; high range ∼ 350 mg Fe/Kg oil-throughout 173 operating hours (∼ 5000 km). At coolant temperatures of 40-60°C and especially at 35-55°C, on the other hand, a rapid increase in Fe content was observed right after approx. 60 hrs, when using good, conventional SAE 15W/40 (API SF/CC) oils. The oil temperature was approx. 55-65°C. High RPM's and engine loads proved to be uncritical for wear in optimized M 100 engines.

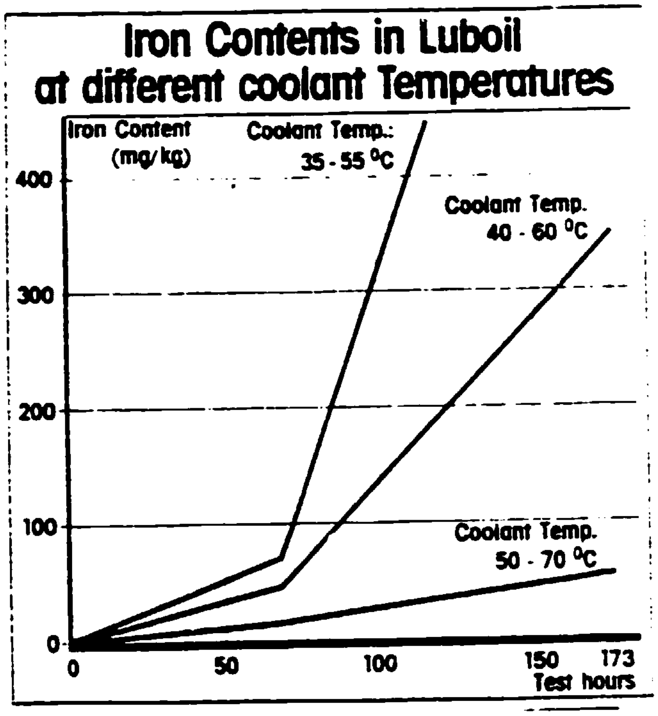


Fig. 4

3.3 The following results of the M 100 passenger car field test are based on more than 3 million Km. running distance. Three types of oil were used and are marked accordingly:

I Conventional multigrade oils
II Conventional single grade oils
III experimental oils.

Oil drain periods were 5000 to 10.000 Km, as required by the engine builders.

3.3.1 Table 9 shows the iron, copper and lead content of the drain oils used in the 1.6 lt engine (carburettor version).

METAL CONTENT in USED OIL

Metallgehalte in Gebrauchtölen

Motor Nr. 1 (1,6 l Vergaser, 63 kW) Carburettor

M 100 Betrieb

	Engine Oil Motorenöl	Number of Samples Probenzahl	Fahrstrecke km (x 1000) Distance	Average Mittelwert, mg/kg (Standardabweichung) (Standard Deviation) min. - max. Iron	Copper	Lead
ventional tigrade Oil	I. Konvent. MB	149	1200	**26** (24) 4 - 202	**9** (8) 1 - 46	**47** (68) 6 - 210
ntional e grade Oil	II. Konvent. EB	40	380	**32** (17) 14 - 86	**5** (4) 2 - 25	nicht bestimmt
xperimental il	III. Experiment	59	365	**33** (37) 8 - 282	**7** (6) 2 - 25	**34** (53) 5 - 383
mparison	**Vergleich: M 15 Motor** (1,6 l Vergaser, 63 kW)					
ventional :igrade Oil	Konvent. MB	60	450	**51** (18) 28 - 177	**18** (8) 9 - 90	bleihaltiger Kraftstoff

Table 9.

The average values - i.e. ~ 30 mg Fe/Kg oil and below 10 mg Cu/kg oil, are similar to the values found in gasoline engines. Only by recognizing the enormous differences between the lowest and the highest values it becomes obvious that some wear problems are to be faced. Fig. 5 and Fig.6 are indicating this situation.

In Fig.5 only 3 results are higher than 80 mg Fe/kg oil (103, 168 and 202 mg Fe/kg oil). In Fig. 6, where results on experimental oils are quoted, only one result (282 mg Fe/kg) is diverting from the normal pattern.

IRON CONTENT in USED OIL FREQUENCY CURVE

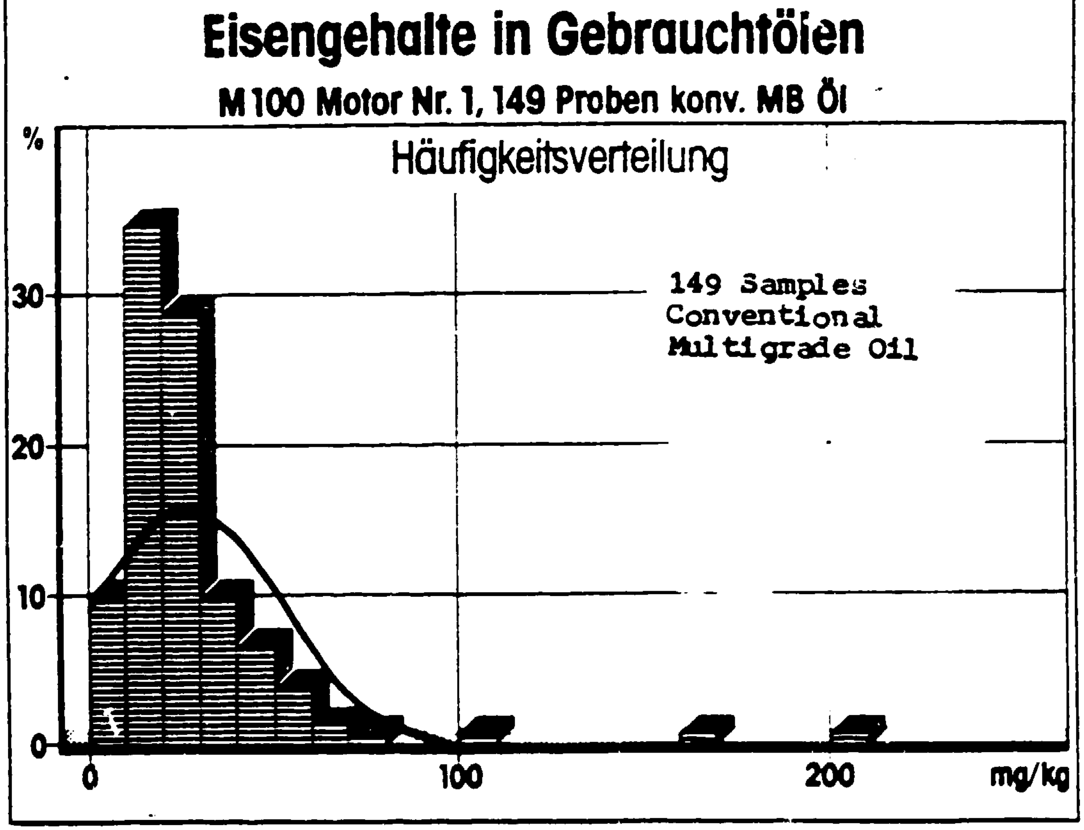


Fig. 5

IRON CONTENT in USED OIL FREQUENCY CURVE

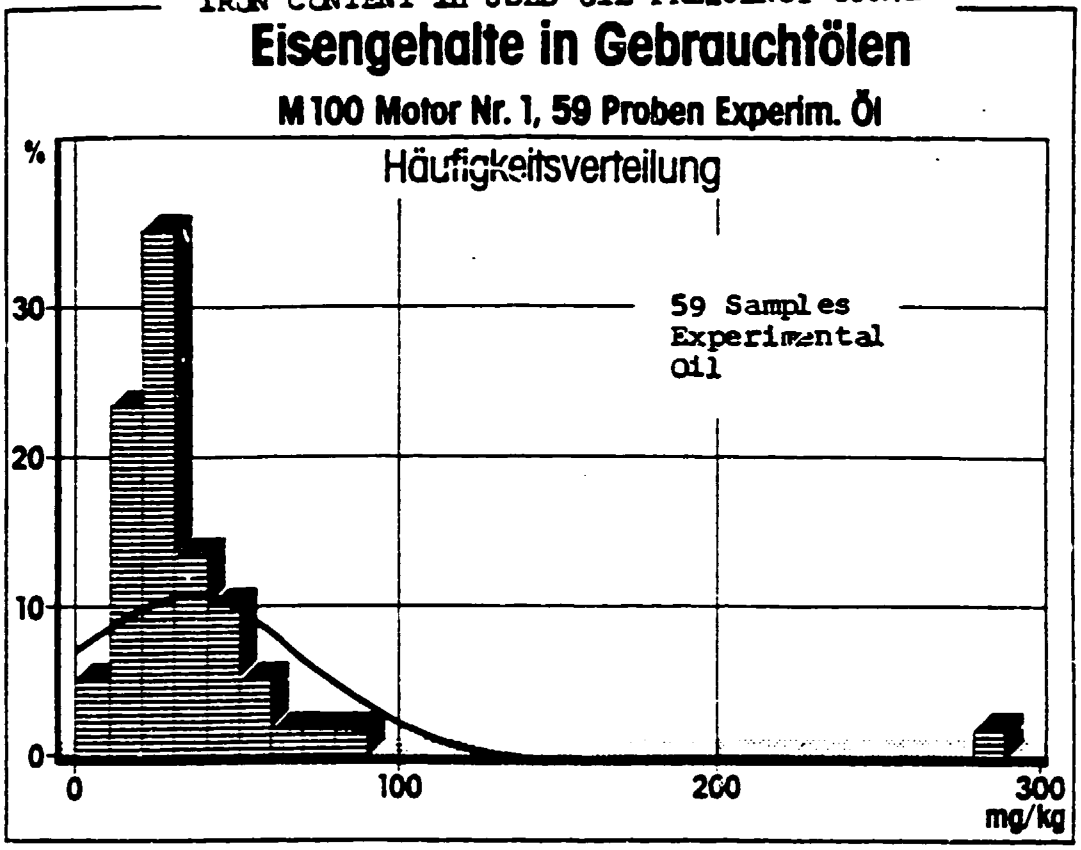


Fig. 6

Fig. 7 shows in more detail the iron content of the drain oil from one car over 50.000 km. In this case at about 25000 km. the iron content became very high (around 300 mg Fe/kg oil) for approx. 5000 km. The TBN's recorded during this periods were still 4,8 to 5.5 (ASTM D 664). Whether during this time some misfunction of the thermostat took place or whether extreme short distance running conditions caused these high wear figures is not known.

This 1.6 ltr Carburettor engine only under extreme driving conditions or due to male-function of the cooling

IRON CONTENT in USED OIL

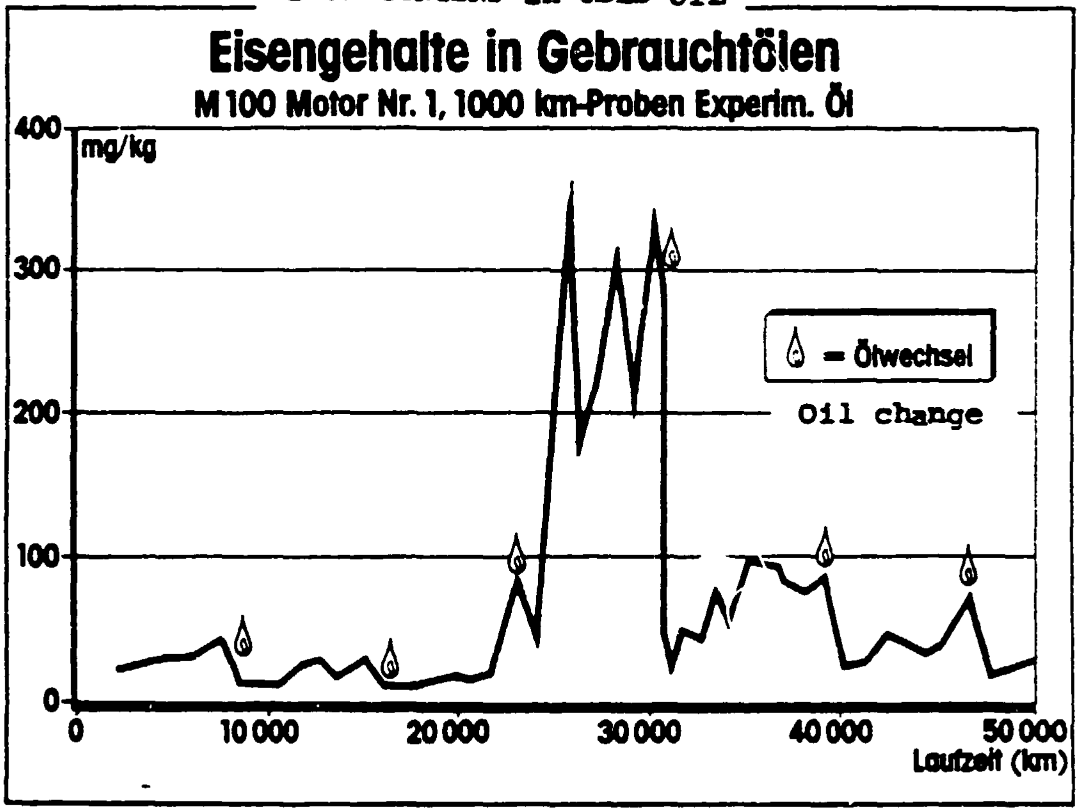


Fig. 7

system an increased engine wear with M 100 is to be expected.

3.3.2 Table 10 shows the iron-, copper and lead content of the drain oils used in the 1.6 lit injection engine. The average figures are higher as usually found in gasoline engines. The wide spread of the simple values is again notable.

METAL CONTENT IN USED OIL

Metallgehalte in Gebrauchtölen

Motor Nr. 2 (1,6 l Einspritzer, 81 kW) Injection

M 100 Betrieb

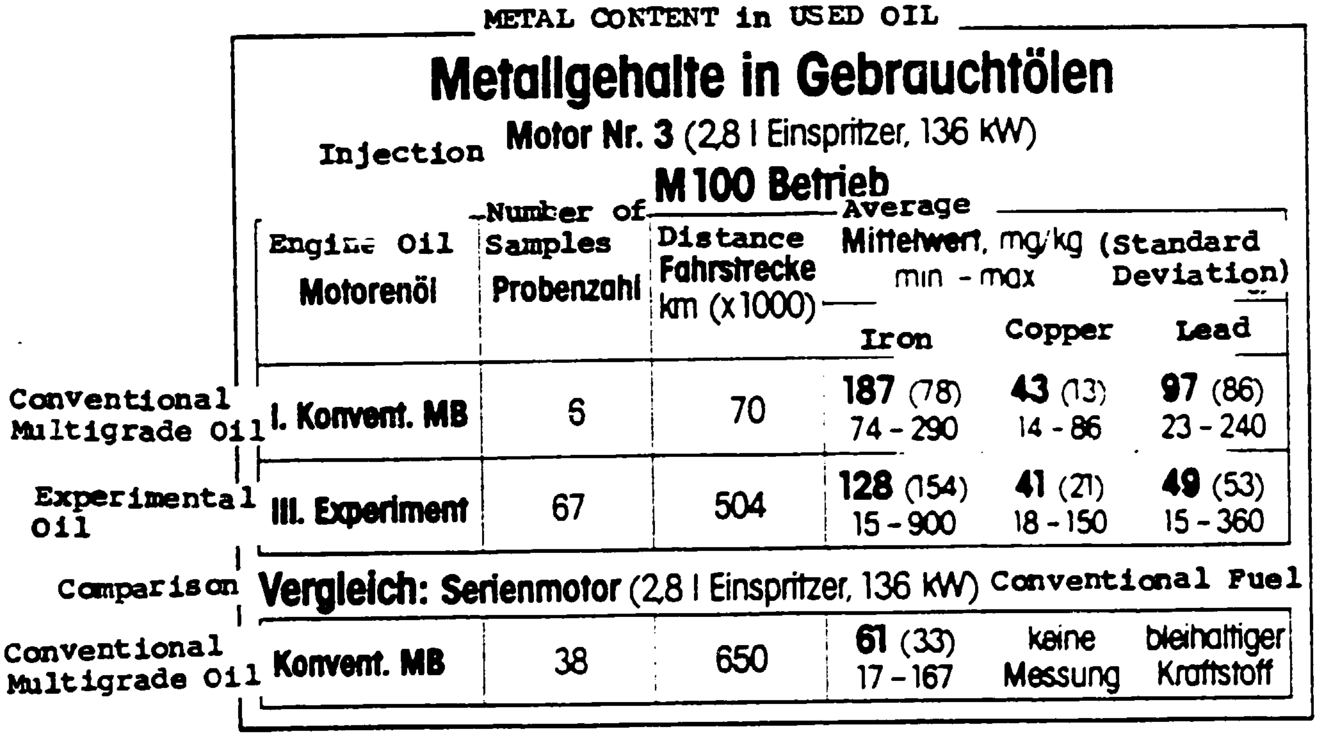
	Engine Oil Motorenöl	Number of samples Probenzahl	Distance Fahrstrecke km (x 1000)	Average Mittelwert, mg/kg min. – max. (Standard Deviation) (Standardabweichung) Iron	 Copper	 Lead
Conventional Multigrade Oil	I. Konvent. MB	42	272	**45** (33) 5 – 173	**15** (10) 1 – 44	**38** (32) 6 – 128
Conventional Single grade Oil	II. Konvent. EB	7	35	**45** (55) 20 – 120	**17** (9) 4 – 26	**52** (34) 13 – 115
Experimental oil	III. Experiment	44	305	**53** (39) 22 – 220	**22** (13) 9 – 55	**135** (130) 24 – 650
Comparison	**Vergleich: M 15 Motor** (1,6 l Einspritzer, 81 kW)					
Conventional Multigrade Oil	Konvent. MB	79	610	**39** (16) 18 – 90	**34** (15) 8 – 66	bleihaltiger Kraftstoff

Table 10

The high copper values might be explained by some copper being brought into the oil via the fuel. Some copper parts in the fuel system might have contributed to this result.

It is interesting to note that in the 1.6 lit engine in both the carburettor and the injection version, the experimental oils did not reduce metal content in the used oil. This seems to indicate that these experimental oils were formulated with the reduction of inlet deposits in mind and not primary thinking of wear reduction.

3.3.3 Table 11 shows the iron, copper and lead content of the drain oils used in the 2.8 ltr <u>injection</u> engine. The tendency is the same as described under 3.3.2.



METAL CONTENT in USED OIL

Metallgehalte in Gebrauchtölen

Injection **Motor Nr. 3** (2,8 l Einspritzer, 136 kW)

M 100 Betrieb

	Engine Oil **Motorenöl**	Number of Samples **Probenzahl**	Distance **Fahrstrecke** km (x 1000)	Average **Mittelwert**, mg/kg min - max (Standard Deviation)		
				Iron	Copper	Lead
Conventional Multigrade Oil	**I. Konvent. MB**	6	70	**187** (78) 74 - 290	**43** (13) 14 - 86	**97** (86) 23 - 240
Experimental oil	**III. Experiment**	67	504	**128** (154) 15 - 900	**41** (21) 18 - 150	**49** (53) 15 - 360
Comparison	**Vergleich: Serienmotor** (2,8 l Einspritzer, 136 kW) Conventional Fuel					
Conventional Multigrade Oil	**Konvent. MB**	38	650	**61** (33) 17 - 167	keine Messung	bleihaltiger Kraftstoff

Table 11

In this engine some of the experimental oils did reduce the wear but others showed extremely high wear figures. This indicates the difficulties still existing. Fig. 7 summarizes the metal content figures in the 2,8 ltr injection engine.

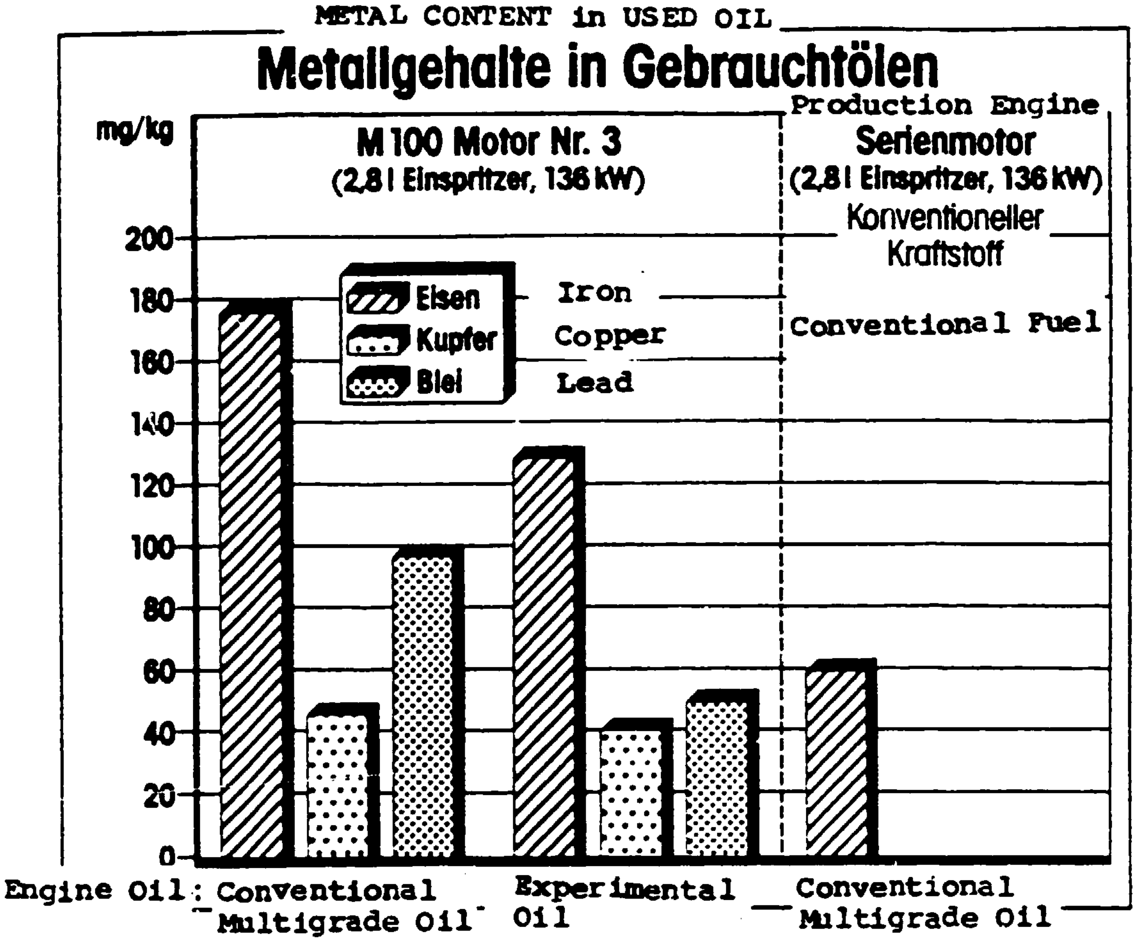


Fig. 7

3.4 Summary of the passenger car field test results:

3.4.1 High quality engine oils (SF/CC) have given trouble in methanol engines using M 100 because heavy deposit formation blocked nozzels and jets. This was particularly detrimental to injection engines. The use of special experimental oils helped to minimize this problem. Further improvement might be possible by changes in the engine construction to reduce or eliminate the contact of methanol droplets or vapor with blow-by gases.

3.4.2 Average wear figures in carburettor methanol engines are not different from normal gasoline engines. However, arduous running conditions, e.g. stop and go traffic and/or low temperature in the cooling system can lead to higher wear rates.

Wear results in injection engines using methanol were higher as in gasoline engines. This might be due to the fact that methanol droplets might enter the combustion room and might reach the cylinder wall. In this case special oils which are under development might help.

In general, it can be stated that the problem should be tackled from the engine construction as well as from the lube oil side.

3. Lecture, dated 19/02/85

WEAR in METHANOL ENGINES
Some results of basic laboratory tests

1. Conclusions from M 100 passenger car field tests.

1.1 In carburettor engines, which were running under favourable conditions, no increase in wear was observed. Only if these engines were running cold because of traffic conditions or malfunction of the thermostat, higher wear did occur.

1.2 In injection engines always higher cylinder liner wear did occur.

Facit: If methanol droplets enter the combustion room and are able to wet the cylinder liner, then higher wear will occur.

2. Methanol and Oil on Metal Surfaces. (1)

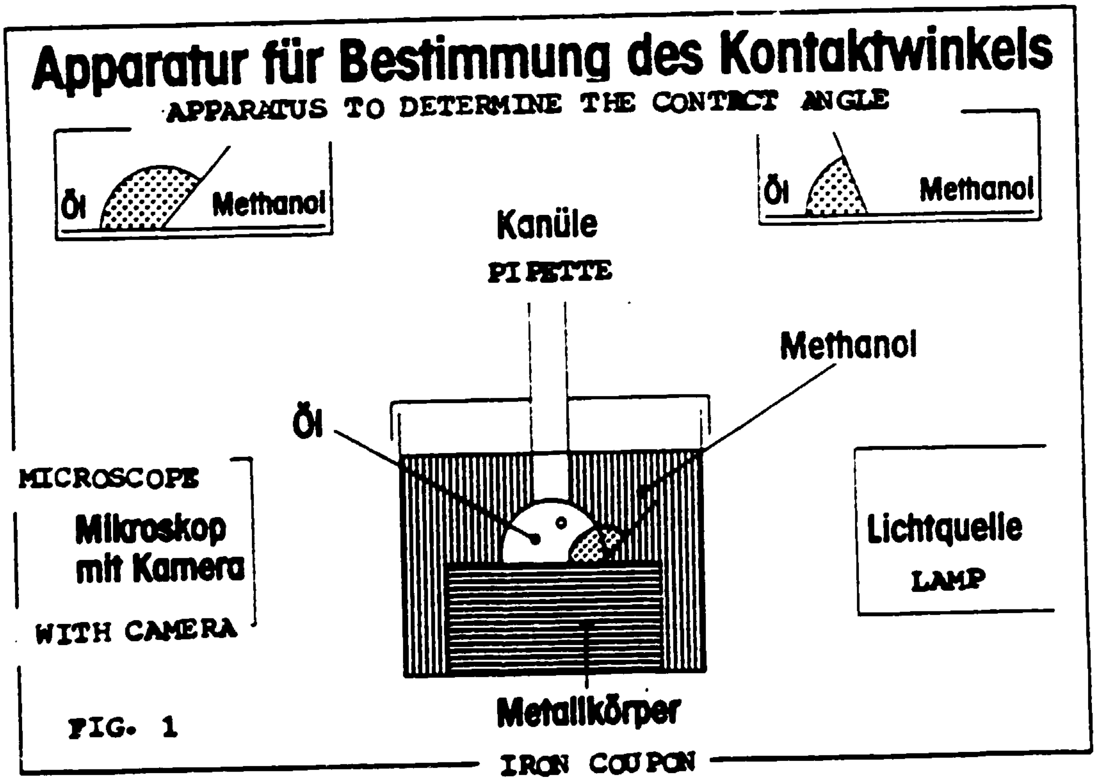


FIG. 1

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(1)= See Literature References under 11.

2.1 We place an iron coupon in a glass container filled with methanol and bring a drop of the test oil on its surface by a pipette. From one side we look with a microscope through the glass container against a light on the other side and observe the oil drop (see sketch in Fig.1). We can notice by the skale in the microscope a certain "contact angle" between the oil and the methanol (see upper part of Fig.1) according to the different types of oils.

If the contact angle is large, the oil tend to form a droplet. This is indicating a rather poor wetting of the metal surface in the presence of methanol.

If the contact angle is small, the oil tend to form a film. The wetting of the iron surface is good even in the presence of methanol.

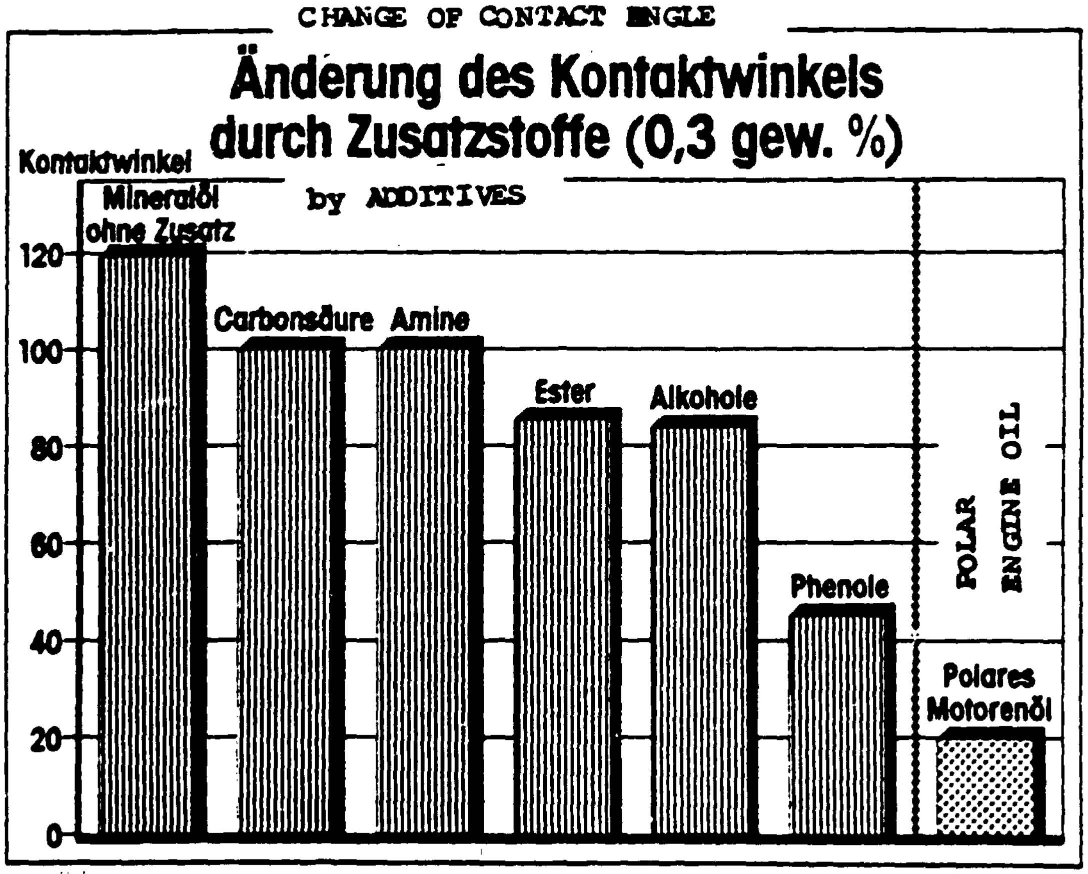


Fig. 2

2.2 In order to change the "wetting power of the oil", we mix some polar components into the oil.

Fig.2 is showing the results in change of contact angle. As an example, Phenol groups can reduce the contact angle to about 50%. The best result in this test was observed with a very "polar engine oil".

2.3 Further observations in this test were:

2.3.1. The change in contact angle also depended on the length of the hydrocarbon chain. If the chain had more than 12 C-atoms no change in contact angle did occur for a given "anchor group".

2.3.2 We did not find any difference in contact angle using iron or chromium surfaces.

2.3.3 We did not find any difference in contact angle by changing the temperature between 25°C and 60°C.

2.3.4 On polished steel surfaces methanol always pushed away and displaced the oil film.

2.3.5 The best high polar engine oil, however, was able to stay at the polished metal surface in the presence of methanol.

3. Piston ring wear in a methanol fueled Ford engine.

3.1 Fig.3 shows the results of an engine test using radionucleid technique to measure piston ring wear. The engine was run 25 min at 3000 RPM and then stopped and subsequently cooled down by pumping water through the system for 70 minutes. This is done to simulate stop and go traffic.

RELATIVE RING WEAR (CHROMIUM)

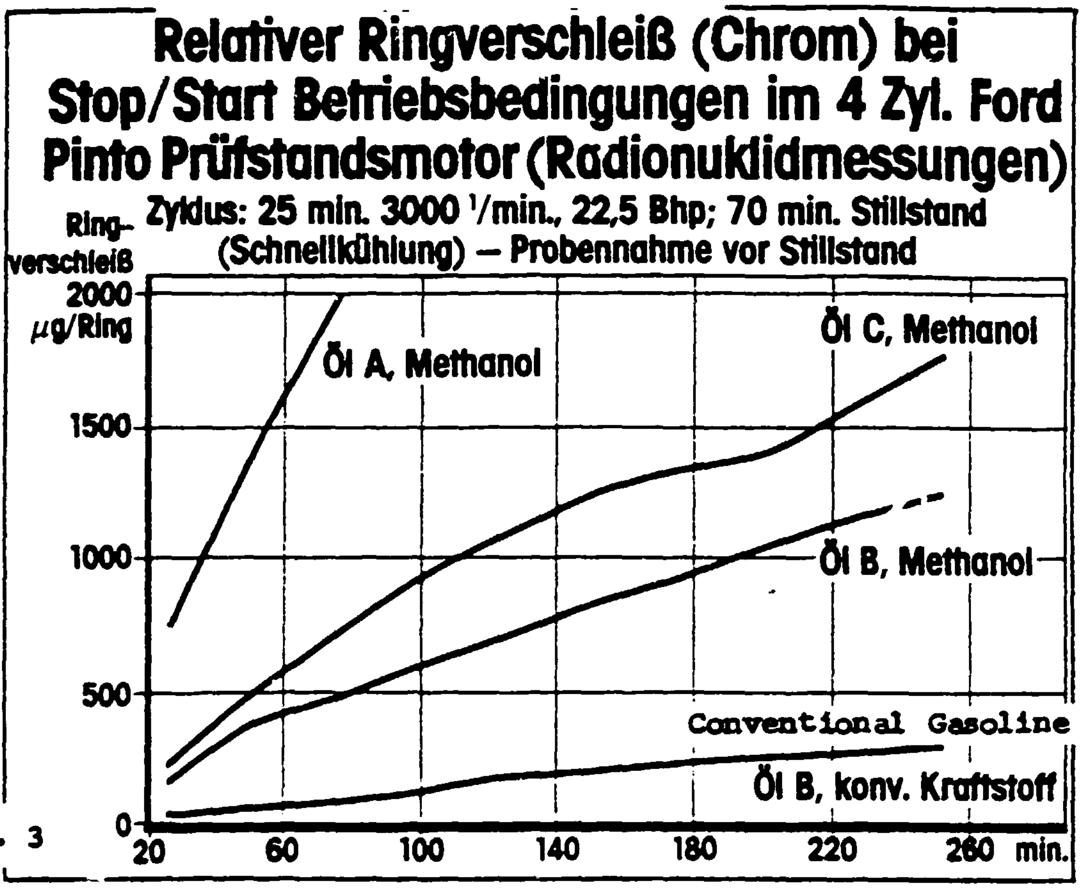


Fig. 3

3.2 By changing the composition of the oil from type A to type C the piston ring wear could be reduced drastically. The lowest wear figures were obtained with oil B, however, using methanol as a fuel still showed about three times the wear then using gasoline (see fig.3) under the test conditions given.

__Facit:__ Special polar engine oils can reduce the engine wear drastically, but even so under stop and go driving conditions the wear with methanol will be higher than with gasoline. Therefore, changes in engine design to improve this situation are advisable.

4. Oil and Methanol Mixtures-Phase Composition (2)

4.1 Mixing a base oil (B) with methanol results in two layers after a short period of standing. This indicates that base oils are not mixable with methanol. Some base oils might pick up a little methanol but it will separate again.

4.2 Mixing a fully formulated oil (F) with methanol results in three layers. The lower layer is predominantly oil containing a small amount of methanol. The second layer is a viscous cream-like layer consisting of a yellowish-white blend of oil and a high concentration of methanol. The third layer is predominantly methanol containing some oil additives.

4.3 The cream layer and the methanol layer can be completely eliminated by warming to boil off the methanol and stirring the mixture to redissolve the oil additives in the oil phase.

5. Emulsions on Hot Metal Surfaces.

5.1 To observe any differences between oil containing water and oil containing methanol, separate samples of water, methanol and a 50 volume percent mixture of methanol in water were mixed with engine oil and placed on a horizontal hot cast iron coupon. The temperature of the metal ranged from approximately the boiling point of the methanol (65°C) to above the boiling point of water (100°C).

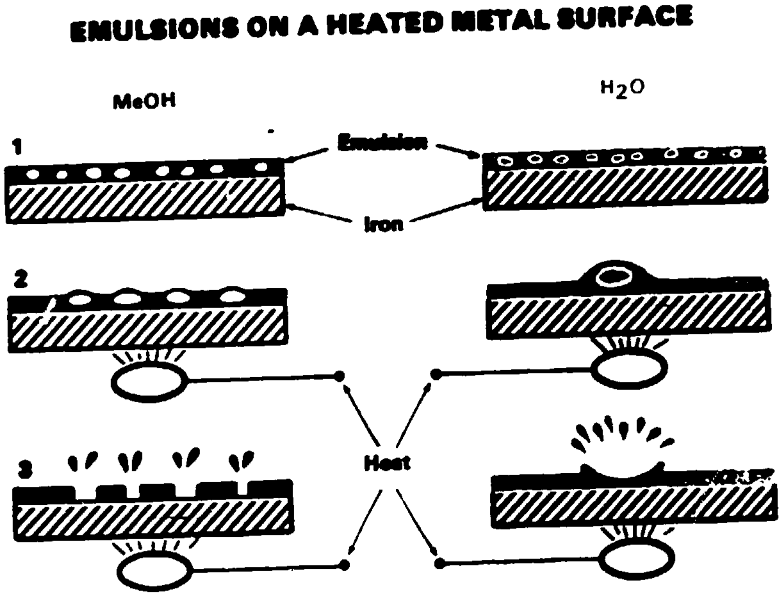

EMULSIONS ON A HEATED METAL SURFACE

Fig. 4

5.2 In oil samples which contained water or water plus methanol small water droplets coalesced to form a large (several millimeters diameter) water drop. A clearly visible film of oil surrounded the water. Those oil surrounded water droplets remained stable for several seconds. Then the droplets released water explosively (flash-boiled). A slight depression which filled in immediately was seen in the oil film.

5.3 Methanol dispersed in oil did not behave in the same manner as water dispersed in oil. Large film surrounded methanol droplets did not form in the methanol oil emulsions.

Instead, as the methanol oil emulsion warmed on the hot iron metal, the methanol coolesced but rapidly boiled out of the oil. This experiment was repeated with the methanol-in-oil emulsion spread in a very thin layer on the metal coupon. As the methanol boiled out of the oil, a small hole formed in the oil. The hole was approximately one millimeter in diameter and remained visible for several seconds.

5.4 These experiments with emulsions indicate that it is possible to cause a break or hole in an oil film when methanol is emulsified in the oil.

6. Phase composition on mixtures (50/50) of Methanol and Oils.

6.1 Methanol plus Arctic polyglycol lubricant shows a clear solution. This sort of mixture could be used in two-stroke Engines, but the optimum fuel/lubricant ratio has to be found out.

6.2 Methanol plus metal deactivator or amine as used in gasolines or aircraft fuels result in clear mixtures. This type of components can be used to inhibit methanol fuels.

6.3 Methanol plus straight-chain primary zincdithiophosphates (C_4-C_5) was largely soluble. This indicates that this type of ZDP can be washed out of an oil by methanol. However, a C_{10} primary branched ZDP was not soluble in methanol. It is possible to find ZDP which would not be washed out by methanol.

6.4 Methanol plus an experimental SAE 15W-30 Engine Oil with no VI-Improver gave two layers. The top layer was creamy, indicating that some additives were solved in methanol.

6.5 Water plus a fully formulated SAE 10W-30 (SF/CC) engine oil gave three layers. On the top the oil came out. The middle layer was cream and the lower layer was milky water. This indicates that some of the additives were forming emulsions with the water.

7. Extraction of Additives by methanol.

7.1 Extraction of oil additives into methanol can be prepared in different ways.

7.1.1 By shaking a 50/50 mixture by volume of oil and methanol and then separating the phases using a separatory funnel or a pipette, depending on the volume of the fluid.

7.1.2 By allowing a stream of methanol to flow over an oil film on a vertical iron surface.

7.2 To determine the composition of the various phases, infrared spectroscopic analysis of the phases were used.

7.3 From a fully formulated engine oil the analysis of the methanol phase indicated the extraction of: a sulfonate (detergent-inhibitor), several types of zinc dialkyldithiophosphate (anti-wear, antioxidant), a phenoxy alcohol (antioxydant) and polymethylmethacrylate (viscosity index improver). These additives were not completely removed from the oil.

Analysis of the viscous cream phase indicated that it was not composed of one or more components extracted from the oil, but was composed of a well-mixed blend of methanol and oil. Experiments in which methanol was mixed with oils containing either viscosity index improver or dispersant-inhibitor package indicated that the dispersant-inhibitor package was the major contributor to the formation of the viscous cream.

7.4 The cream phase of oil from a methanol fueled vehicle contained more of the methanol-soluble additives (ZDP, sulfonate and a phenol compound) than the oil phase. Thus, methanol can cause the reduction in concentration of various additives in engine oil when methanol is mixed with the engine oil and allowed to stand. A stream of methanol flowing over an engine oil film on a vertical surface also extracted additives from the oil.

During low temperature engine operation, liquid methanol might come in certain constructions in contact with the engine oil in the upper cylinder region of the engine. The engine oil additives are most likely to be removed from the base stock in this region. Corrosion, wear, oil oxidation etc. are most likely to be severe here.

Analysis of the bulk oil for additive depletion will probably not detect the problem, since the additives would be re-introduced to the oil where the methanol evaporates.

8. Action of Additives - Zincdithiophosphate as an Example (3)

8.1 Fig. 5 shows as a sketch the reaction of phosphite on an iron surface. First only adsorption (physical reaction) takes place. Under condition of hydrolysis, which occurs with the water present from combustion, the second step is "chemical adsorption". This provides already antiwear properties. In the third stage after further hydrolysis real chemical reaction takes place. Now antiscuffing properties are observed on the metal surface.

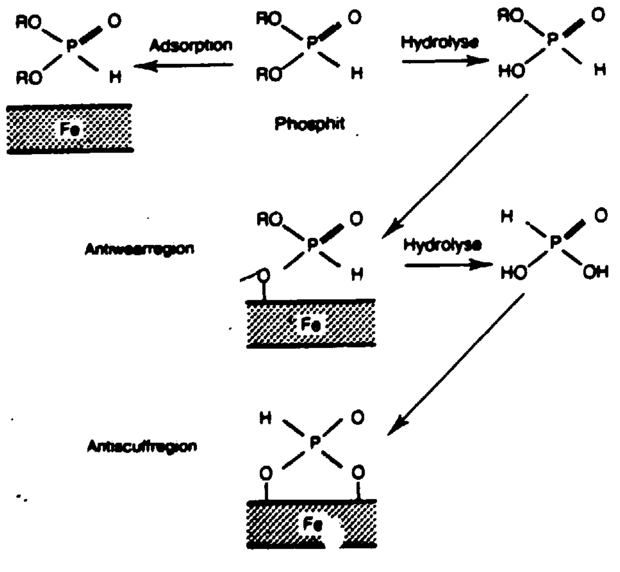


Fig. 5

8.2 Based on different raw material 3 different types of zincdialkyldithiophosphates are produced (see Fig. 6).

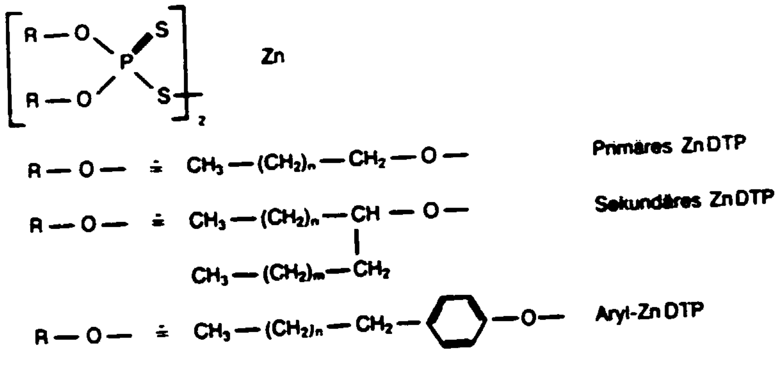


Fig. 6

Their reaction in respect of thermal stability, hydrolytic stability and anti-wear protection as well as cost are different.

Fig. 7 is indicating these differences as trends but they can also vary with the chain length of the hydrocarbon component. To balance the final additive package a mixture of zincdialkyldithiophosphates is used.

ZINC DITHIOPHOSPHATE TYPES

Performance Parameter	Aryl	Primary Alkyl	Secondary Alkyl
Thermal Stability	Best	Medium	Worst
Anti-Wear Protection	Worst	Medium	Best
Hydrolytic Stability	Worst	Medium	Best
Relative Cost	High	Low	Low

Fig. 7

9. Corrosive Wear of Methanol and its Combustion- Products on Iron (2).

9.1 To show and simulate crevice corrosion a sample of an engine cylinder liner was coated with a thin film of SAE 10W-30 SF/CC quality oil and divided in three regions. In the first region water was flushed over the engine oil film. Then iron chips saturated with water (a simplified representation of the crevice between the cylinder and the piston ring) were placed on the cylinder bore.

In the second region, the oil film was flushed with methanol before iron chips which were covered with methanol were placed on the cylinder bore.

In the third region, iron chips covered with methanol were placed on the cylinder bore without any initial flush.

Results: Methanol, by itself, did not promote iron oxide formation.

On the other hand, water, even through an oil film promoted iron oxide formation. Thus, water contributed more to rust formation than methanol under the experimental conditions used (see sketch Fig. 8) (See next page)...

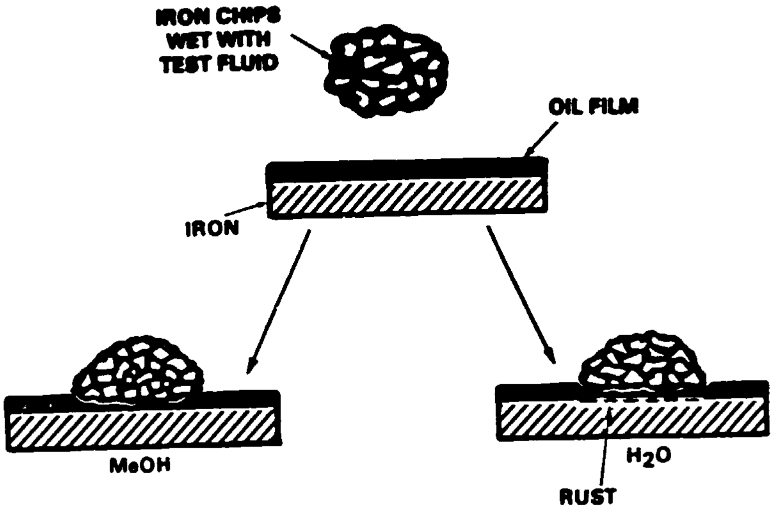
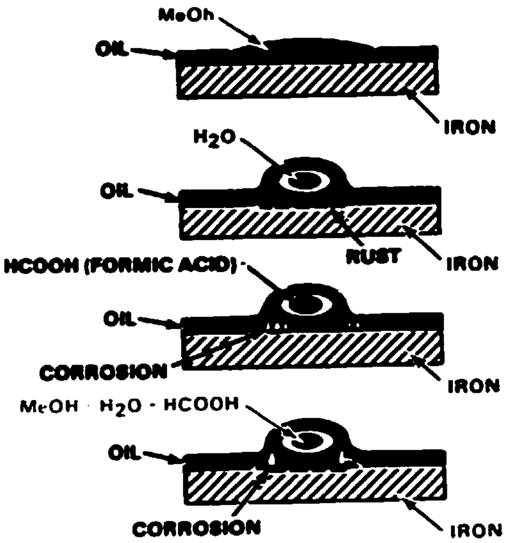

EFFECTS OF FLUID ON CREVICE CORROSION

Fig. 8

9.2 To see the corrosive potential of the components of interest in blow-by gases (water, formic acid and water) a series of tests was conducted.

A small drop of test fluid ($\sim 1{,}5\ \mathrm{mm}^3$) was applied to a horizontal cast iron coupon (ASTM D 2570-73) and allowed to evaporate at room temperature. The corrosion spot which formed was examined visually, microscopically and profilometrically (surface roughness) for evidence of corrosion products and surface contour changes. In a second series of tests a thin oil film was placed on the iron surface before applying the test fluid.



CORROSION FROM DROPLETS OF BLOW-BY COMPONENTS

Fig. 9

Results: Water and formic acid caused observable changes in the surface of the iron, as determined visually or microscopically, whereas methanol did not.

The presence or the absence of a thin (3.4 micrometer) oil film on the metal surface made very little difference in the results except in the measurement of the evaporation rate of a water droplet.

In all samples which contained formic acid, at a concentration as low as 0.1 percent, a ridge formed at the edge of the test spot. This doughnut-shaped ridge was easily detected with either a microscope or a profilometer. Sample profilometer traces are shown in Fig.10. The formation of a ridge at the outer edge of a spot of test fluid suggests that material was dissolved and transported by the test fluid.

(See Fig.10 next page).

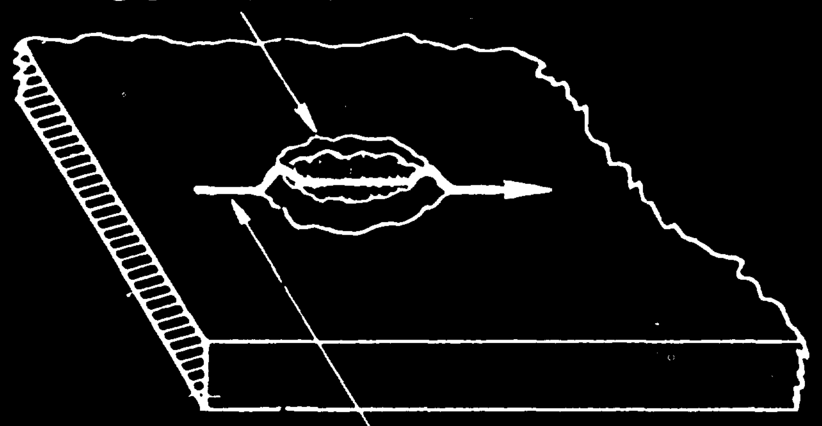
Of the fluids tested, methanol has the greatest tendency to spread. A large increase in the time of evaporation of the test fluid in the presence of an oil film indicates that the oil film has surrounded the droplet of test fluid. Water exhibited the greatest increase in evaporation time in the presence of an oil film. Methanol exhibited no increase in evaporation time, thus emplying that water droplets become surrounded by oil, but methanol droplets do not.

9.3 An attempt was made to determine the effectiveness of additives with respect to corrosion. Using an apparatus as shown in Fig.1 the test fluid was applied to the cast iron coupon. The level of the test fluid was kept in a predetermined operating range.

(Figs. 11 & 12 on page 17)

Results: In these tests, almost no iron oxide was formed in the samples which were made alkaline (pH greater than 7) by the addition of an amine to the test fluid. The only rust seen in those samples was the small spot immediately under the tip of the glass dropper holding the test fluid. These results suggest that it may be possible to control iron oxide formation by the use of enough corrosion inhibitor to keep the pH of the blowby condensate alkaline.

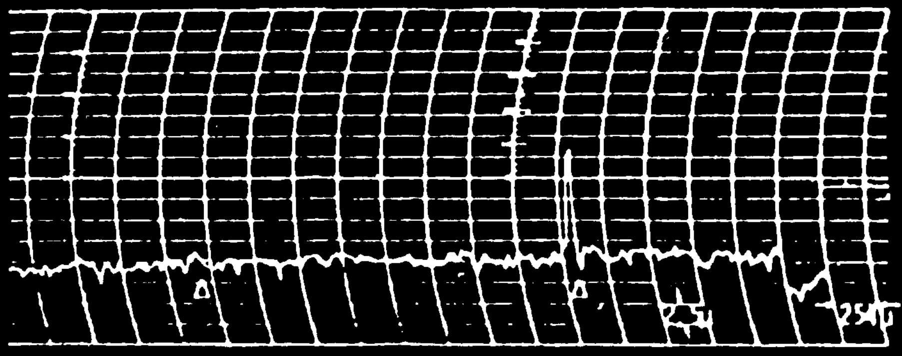
PROFILOMETER TRACES



CORROSION SPOT

PATH OF PROFILOMETER STYLUS

0.1% FORMIC ACID



FORMIC ACID ON OIL

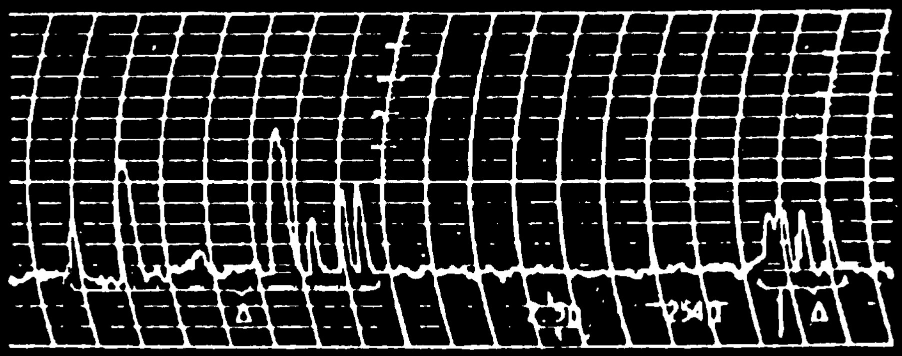


Fig. 10

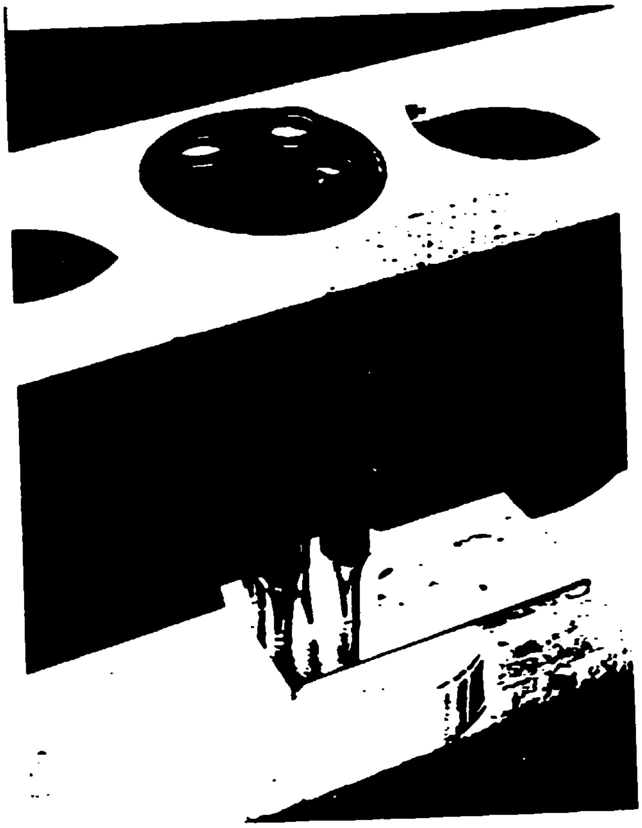


Fig. 11

Corrosion Inhibition **Inhibition de la corrosion**

Sample	1	2	3	4	5	Echantillon
Composition						Composition
H_2O	100.0	99.8	89.9	89.7	89.5	H_2O
MeOH	0.0	0.0	10.0	10.0	10.0	MeOH
HCOOH	0.0	0.0	0.1	0.1	0.1	HCOOH
Inhibitor	0.0	0.2	0.0	0.2	0.4	Inhibiteur
pH	5	10	3	6	10	pH
% Rust	100	0-5	100	100	5-10	% Rouillé

Fig. 12

However, this will be an expensive route to cure the problem of corrosion. An important aspect to be observed would be the influence of "alkaline blowby"on the lube oil.

10. Last but not least: A Possible New Additive Base-Jojoba Oil.

10.1 Jojoba oil is a natural product with no harmful reaction to human health. This might become an important factor in the future since the toxicological problems are observed more carefully now a days.

10.2 Jojoba oil is still very rare and therefore expensive. It is used as a base for cosmetics. In future the price will come down because a large area of jojoba-plantation has been arranged in the past few years. It is my guess, that in 5-7 years jojoba oil will be commercially available for limited additive use.

10.3 Jojoba oil has a strong "anchor" group in the centre of the molecule. It therefore improves the so-called "lubricity" of oils also, if contained in small amounts only.

Jojoba oil has a very low volatility of only 1 % whereas mineral oil of similar viscosity would have a volatility of ~15 %.

Jojoba oil has a very high viscosity index of 234 whereas good mineral oils will have a VI of ~ 100.

The coefficient of friction was improved by 10% after adding 5% jojoba oil to a mineral oil (Tannert-Test). In an motored engine the friction losses were reduced by 4 % when adding 10 % jojoba oil to the engine oil.

10.4 Future development in the field of jojoba oil as an additive base will include the addition of sulfur and/or phosphorus. If we will succeed to make jojoba oil at least partly soluble in methanol, it would be a very valuable component for a methanol- 2 stroke-Oil.

11. Acknowledgements: I would like to thank Dr.Shirley E. Schwartz, General Motors Research, USA for providing me with the excellent slides for this lecture which is actually based to a great extent on work by Dr.S.E.Schwartz and her co-workers.

12. References:

(1) Erfahrungen und Erkenntnisse mit Motorenolen
im Betrieb mit M 100-Kraftstoff.

Dr. H. Krumm, Deutsche Shell, AG Hamburg.
Dr. K.M. Riches, Shell Research Thornton.
Dr. C. Pinnington, " " "
Not jet published.

(2) Laboratory Studies of the Effects of Methanol Fuel
on Engine Oil and Materials

Dr. Shirley E. Schwartz, General Motors Research,
May 21, 1984, GMR-4589; F & L- 782.

(3) Motorenole

Publication of Quality Department of Deutsche BP-AG
Hamburg 1981.

APPENDIX 4.

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
UNITED NATIONS DEVELOPMENT PROGRAMME
Assisting : INDIAN INSTITUTE OF PETROLEUM

ADDRESS FOR CORRESPONDENCE :
INDIAN INSTITUTE OF PETROLEUM
P.O. I.I.P.
DEHRA DUN - 248 005. INDIA

Your Ref.

Our Ref. IND/82/001/-05

IND/82/001–APPLICATION OF ALTERNATIVE
FUELS FOR INTERNAL COMBUSTION ENGINES

23.1.1985

Visit Report by Hans-C. WOLFF, UNIDO Expert

1. Visit to: LUBRIZOL INDIA LIMITED (LIL), Bombay
   a) Research Center, Thane-Belapur Road,
   b) Sales Office, Bombay, Delstar, 9A,
   S. Patkar Marg.

2. Date: 18 - 20 Jan.1985.

3. Discussions with:

3.1 Mr. Charles C. Colyer, Chief Technical Adviser from
THE LUBRIZOL CORPORATION
Wickliffe, OHIO 44092, USA.

3.2 Dr. K.L. Mallik, Manager Research and Development,
LUBRIZOL INDIA LIMITED (LIL)

3.3 Dr. Sudarshan Sarma, Manager R & D, LIL

3.4 Dr. U. Sripathi Rao, Assistant Manager R & D, LIL

3.5 Dr. R.K. Shukla, Assistant Manager R & D, LIL

3.6 Dr. R.L. Mendiratta, Assistant Manager R & D, LIL

3.7 Mr. R.A. Rao, General Manager Sales, LIL

3.8 Mr. B. Sanghavi, Manager Technical Services, LIL

4. Reason for the visit:

4.1 LUBRIZOL INDIA LIMITED (LIL) is the only company with large scale production for engine oil additives in India. Any development of new additives, e.g. for methanol engines, should therefore take notice of these production possibilities.

4.2 Mr. C.C. Colyer (3.1) is visiting LIL for 10 days only. This gave the unique opportunity to discuss with him and the research staff of LIL the development of additives for methanol engines in the USA and the possibilities of producing similar material in the LIL Bombay plant.

4.3 Mr. C.C. Colyer was also informed by H.C. Wolff about the latest results on methanol engine oils in Germany in order to enable him to incorporate these in the support of LIL to the UNDP-Project at IIP.

5. Result of the visit:

5.1 On advice of Mr. C.C. Colyer THE LUBRIZOL CORPORATION, USA, will send on short notice an additive sample for

4-stroke methanol engines to LIL for preparing 100 l ready engine oil SAE 20W-40 in Indian base oil.

5.2 This additive sample will be based on the product OS 66 839 (see Appendix), which has given good results in the modified Ford V-D methanol (2,3 l) engine test in U.S.A. The additive will be based on components which can be produced in the LIL Bombay plant later on. It can, therefore, be called, "Indian type additive".

5.3 The 100 l SAE 20W-40 oil (5.1) will be sent as soon as possible to IIP to be engine tested in the 1 Zyl. Kirloskar engine fitted with radioactive piston rings in the course of the UNDP-Project. It will thus be run in comparison to the field tested methanol engine oil supplied via H.C. Wolff by Bank of America (Formula 222 A) and against the "base line oil", which was used previously by IIP.

5.4 Mr. C.C. Colyer stated that at 21.12.84 5 gallons of OS 59 770 was shipped from Wickliffe to LIL. This is a 2-stroke oil to be used in methanol engines. It is expected to show similar performance then the sample tested by IIP previously. However, OS 59 770 could be produced in larger quantities as compared to the previous sample, which was on laboratory seale only. LIL will forward OS 59 770 to IIP for engine testing in the course of the UNDP Project immediately.

5.5 Mr. C.C. Colyer is organising the lubricants section of the Pacific International SAE Conference (Nov.1985) in Djakarta, Indonesia. He is prepared to accept a paper of the IIP, as discussed with Mr. S. Singhal earlier. The matter is urgent because the abstract should be with the printer already. An IIP-Engine Laboratory Report on engine wear studies by using radioactive rings in a 1 Zyl Kirloskar engine, which H.C. Wolff had with him, was shown to Mr. C.C. Colyer. This report, which was prepared by Mr. A.K. Gondal and Dr. P.C. Nautiyal would be acceptable to Mr. C.C. Colyer, if the management of IIP is deciding within the next two weeks on its publication.

6. Actions to be taken:

6.1 Methanol engine oil additive for 4-stroke engines, similar to OS 66 839 to be sent from Wickliffe, USA to LIL, India in order to start engine testing at IIP in March, 1985.
Action: Mr. C.C. Colyer, Dr. K.L. Mallik.

6.2 Mixing of 100 l SAE 20W-40 "4-stroke Methanol Engine Oil-Indian Type" by LIL using Additive supplied by 6.1.
Action: Dr. K.L. Mallik.

.... /

6.3 Supply of 100 l oil (6.2) from LIL to IIP as fast as possible, to start engine testing at IIP in March, 1985.

6.4 LIL to supply 5 gallons 2-stroke oil received from USA to IIP for engine testing.
Action: Dr. K.L. Mallik, Dr. St. Radzimirski, UNIDO Expert.

6.5 IIP-Management to decide on publication at Pacific International SAE Conference.
Action: Mr. S. Singhal.

7. Distribution of the report

7.1 UNDP- New Delhi - Dr. K. Hussein

7.2 LIL, (2x) Mr. C.C. Colyer, Dr. K.L. Mallik.

7.3 IIP, (3x) Mr. S. Singhal (2x), Dr. St. Radzimirski.

7.4 IIP,- H.C. Wolff.

H-Ch. Wolff

(H.C. Wolff)
UNIDO EXPERT

Appendix to the visit report H-C. WOLFF
LUBRIZOL INDIA LTD
18-20 Jan. 1985

Table I

Inspection Characteristics of OS 66839

Table II

Methanol Fueld 2.3 l Ford Testing
Modified Ford V-D Test.

Table I

Inspection Caracteristics
of OS## 66839

	Concentrate	Blend
OS##66839	100 % w	21.0 % w
LZ 7322		2.5 % w
LZ 6662		0.3 % w
Base Stock		130N
Analytical Values		
Sulfated Ash, %	6.71	1.41
Zinc, %	0.71	0.15
Phosphorus, %	0.64	0.13
Calcium, %	1.71	0.33
TBN	45.0	9.5
Specific Gravity	0.96	0.89
Vis at 100°C, cSt	210	11.2
CCS at -20°C, cP	—	35.0

Methanol-Fueled 2.3 l Ford Testing

Modified Ford V-D Test

Blend Ident:			Motorcraft (factory fill)	Motorcraft (interim)	Lubrizol Expt'l	OS#59567 Type
SAE Vis. Grade			30	10W-40	10W-30	10W-30
Viscosity Improver			None	OCP	2.5 % LZ 7322	2.5 %w LZ 7322
Additive			Paramins	Lubrizol SF/CC	20.15 %w Expt'l	21 %w OS#66839
ASTM SO_4 Ash			2.65	1.1	1.5	1.4
ord V-D	Gasoline Engine Requirements	Ford Data	Lubrizol Data			
Deposits						
Engine Sludge	9.4		9.6	9.5	9.5	9.6
Engine Varnish	6.6		9.3	9.0	9.1	9.3
Piston Varnish	6.7		9.5	8.4	8.8	9.2
Wear						
Cam Lobe Wear, max/av in mils	2.5/1.0	0.9/0.7	11.7/5.9	6.1/1.2	13.6/5.2	2.3/1.6
Cyl. Bore Wear Inc. Transverse max/av in mils		1.1/0.5	2.5/1.2	5.9/4.2	1.9/0.8	1.6/0.8
Rod Brg. Wt. Loss, max/av, in mils		35.3/18.1	57.2/53.3	141/112.0	23.1/20.1	20.3/18.1
Valve Stem to Guide Clearance, av. in mils		3.9	3.3	3.0	2.5	1.8
Oil Consumption, qts.		2.75	0.97	1.38	0.88	1.25
Blowby, CFM			1.70	1.83	1.70	1.84

WBC/ls
11-13.84

APPENDIX 5a

DU PONT DCI-11
CORROSION INHIBITOR
FOR
GASOLINE-ALCOHOL FUELS

PLMR-12-85

FEBRUARY, 1985

Dr. Perry Polss, Sr. Supervisor
Petroleum Additives Division
E. I. du Pont de Nemours & Co., Inc.
Petroleum Laboratory
Wilmington, Delaware 19898

SUMMARY

DCI-11 corrosion inhibitor has been developed by Du Pont for use in gasohol. It also is effective for use in gasoline containing methanol and other alcohols. DCI-11 can be used in conjunction with DMA-53 carburetor detergent to provide multifunctional properties including corrosion inhibition, carburetor detergency, antiicing activity, and exhaust emission control.

DCI-11 is recommended for use at concentrations up to 8.6 mg/L. It is effective in controlling corrosion of automotive fuel system metallic parts. The product has been tested in a number of different test methods with good success.

DMA-53 which can be used in conjunction with DCI-11 is an effective carburetor detergent for use with gasoline-alcohol fuels. Its use with top cylinder oil will provide effective control of intake system deposition. DCI-11, when used with DMA-53, provides additional corrosion protection which is necessary when alcohols are incorporated into gasoline blends. A blend of DCI-11 and DMA-53 can be used for convenience.

DCI-11

DCI-11 is a corrosion inhibitor developed by Du Pont for gasohol -- a blend of 90% gasoline and 10% ethanol. DCI-11 also is effective in gasoline containing other alcohols like methanol cosolvent blends.

Corrosion Inhibitor Performance - The effectiveness of DCI-11 in controlling corrosion experienced with gasohol is shown in Table 1. ASTM Method D665B which uses synthetic sea water was conducted. At 8.6 mg/L, DCI-11 gave a rust rating of 7% rust compared to 75% rust with no inhibitor present. DCI-11 was effective in deactivating the corrosive contaminants present in the ethanol as well as controlling the corrosion originating from the gasoline even in this extremely corrosive sea water environment.

DCI-11 also is effective in controlling corrosion with gasohol in the NACE TM-01-72 test method as shown by the results presented in Table 2. An A rating with 0% rust was obtained with 5.6 mg/L. DCI-11 also is effective in controlling corrosion which can occur with ethanol in the absence of gasoline. The performance of DCI-11 was determined in the NACE TM-01-72 test method in tests with both 5 and 10% water added to the methanol. Results in Table 3 indicate that a very low level of DCI-11 will give an A rating.

Corrosion Performance - Methanol and Cosolvent Alcohols - In long-term storage tests, DCI-11 at 8.6 mg/L in gasoline containing 5% methanol and 4.2% of a mixture of cosolvent alcohols was effective in preventing corrosion. After 2 months' storage at 110°F (38°C), no rust was observed in the NACE TM-01-72 test method whereas the control fuel caused 60% rust. Results are presented in Table 4.

Two-phase corrosion tests were conducted with the eight commonly used automotive fuel system metals. Enough water was used in the test to form a substantial lower phase.

Test specimens were stored in the two-phase system for one month at 110°F (38°C). This is a very severe test since the elevated temperature accelerates the corrosion effects and the one-month storage period is very long compared to the 24 hour test period which is commonly used.

DCI-11 provided excellent corrosion protection of the critical steel, terneplate, aluminum and brass metals as reflected by Table 5. Some discoloration of the copper was observed which probably reflects the copper passivating effect of the product. DCI-11 was effective in providing protection of the critical metals in the water phase. The slight alteration of the cadmium and zinc surfaces in the water contact areas is not considered serious in view of their location in the fuel system and the overseverity of the test method.

Product Literature - A product data sheet for DCI-11, Du Pont Corrosion Inhibitor, is provided in Appendix 1.

DMA-53

DMA-53 is attractive as a multifunctional gasoline additive in fuels containing methanol and cosolvent alcohols. It provides carburetor detergency and, in conjunction with top cylinder oil, also provides intake valve deposit control.

The performance of DMA-53 is described in Du Pont Petroleum Laboratory Report PLMR 23-84, "DMA-53 - A Report On Its Properties and Performance." This report covers the benefits of using DMA-53 including carburetor detergency, corrosion protection, carburetor icing control, and intake system deposit control.

In this report, the performance of DMA-53 in gasolines containing alcohols will be described.

DMA-53 at 23.6 mg/L was very effective in controlling carburetor deposits when used in gasoline containing methanol and tertiary-butyl alcohol as shown in Table 6. The addition of methanol and tertiary-butyl alcohol to gasoline caused major increases in carburetor deposition in this test series.

Product Literature - A product data sheet for DMA-53 Multifunctional Additive is provided in Appendix 2. Physical properties of a blend of DMA-53 and DCI-11 are in Appendix 3.

Table 1

EFFECT OF DCI-11, CORROSION INHIBITOR, IN GASOHOL

ASTM D665B: 100°F, 4 Hours, Synthetic Sea Water,
Mild Steel Billet

DCI-11, mg/L	ASTM D665B % Rust
0	75
2.8	70
8.6	7
14.2	1

Table 2

EFFECT OF DCI-11, CORROSION INHIBITOR, IN GASOHOL

NACE TM-01-72: 100°F, 4 Hours, Distilled Water,
Mild Steel Billet

DCI-11 mg/L	NACE TM-01-72 Rust Rating
0	E (95)
1.4	B (25)
2.8	B (5)
5.6	A (0)

( ) % Rust

Table 3

EFFECT OF DCI-11, CORROSION INHIBITOR, IN ETHANOL

NACE TM-01-72 Method

Water, Vol %	DCI-11 mg/L	Rust Rating
5	0	E (90)
	1.4	A (0)
	2.8	A (0)
	5.6	A (0)
10	0	E (80)
	1.4	A (0)
	2.8	A (0)
	5.6	A (0)

( ) % Rust

Table 4

EFFECT OF DCI-11 ON THE CORROSION TENDENCY OF FUELS STORED FOR EXTENDED PERIODS

Fuel Stored for 12 Weeks at 110°F
No Metal Coupons in Stored Fuels
NACE TM-01-72 Test Method (Steel)

	NACE Rust Test Rating		
Weeks @ 110°F:	0	4	12
Gasoline + 5M + $4.2M_xAl$	B (5)	C (30)	D (60)
Gasoline + 5M + $4.2M_xAl$ + 8.6 mg/L DCI-11	A (0)	A (0)	A (0)

( ) % Rust

Table 5

STATIC TWO-PHASE CORROSION TEST OF GASOLINE-ALCOHOL FUELS WITH ADDED WATER

(4 Weeks Storage at 110°F)

DCI-11 Conc = 8.6 mg/L

	HC Phase		Water Phase	
	Control	DCI-11	Control	DCI-11
Terneplate	Clear	Clear	Etched	Clear
Tin Plate	Clear	Clear	Lt Discolor	Clear
Cadmium Plate	Clear	Clear	Pitted	Etched
Zinc Pot Metal	Clear	Clear	Pitted	Etched
Admiralty Brass	Lt Discolor	Clear	Hvy Discolor	Lt Discolor
Copper	Hvy Discolor	Hvy Discolor	Etched	Clear
Aluminum	Clear	Clear	Etched	Lt Discolor
1010 Grade Steel	Clear	Clear	Pitted	Lt Discolor

Table 6

EFFECT OF DMA-53 ON CARBURETOR DETERGENCY IN GASOLINE-ALCOHOL FUELS

CRC Test

Fuel Description	DMA-53 mg/L	CRC Rating	Deposit Wt., mg.
Phillips J	-	6.4	14.9
Phillips J + 2.5M + 2.5 TBA	-	4.7	33.9
Phillips J + 2.5M + 2.5 TBA	23.6	6.5	11.1
Phillips J + 2.5M + 2.5 TBA	-	4.1	75.5
Phillips J	-	6.1	22.3

Appendix 1

DCI-11

DU PONT
CORROSION INHIBITOR
NO. 11

DCI-11 . . . Gasoline additive providing corrosion inhibition to alcohols and fuel/oxygenate blends.

Petroleum Chemicals

Petroleum Laboratory
Wilmington, DE 19898

[illegible] [illegible]

APPLICATION—To impart corrosion inhibition to alcohols and gasoline/oxygenate blends.

CONCENTRATION—Varies with oxygenate level and corrosivity. We recommend adding DCI-11 to the oxygenate so that a concentration of 2 to 4 ptb (6 to 12 mg/L) is provided in the finished gasoline/oxygenate blend.

PROPERTIES—(Typical)

Appearance	Clear amber liquid
Specific Gravity, 60/60F (16/16C)	0.94
Pounds/gallon, 60F (16C)	7.8
Ash, wt %	0.0
Flash Point, PMCC, F (C)	98 (37)

Viscosity:

Temperature	cSt	SUS
100F (38C)	41	192
32F (0C)	322	1486
0F (−18C)	1290	5939

ADDITION—Concentrated or in stock solution with aromatic solvents using a proportioning pump or batch addition. Dilution with 20 vol % xylene allows pumping at −20F (−29C).

PRECAUTIONS IN HANDLING—Flammable. Causes irritation. Keep away from heat, sparks and flame. Avoid contact with eyes, skin and clothing. Keep container closed. Use with adequate ventilation. Wash thoroughly after handling.

In case of fire, use water spray, foam, dry chemical or CO_2.

FIRST AID—In case of contact, immediately flush eyes with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Call a physician. Flush skin with water. Wash clothing before reuse.

Appendix 2

DMA-53

DMA-53

MULTIFUNCTIONAL ADDITIVE

DMA-53. . . is a versatile multifunctional additive for use in motor gasolines. It is ashless, phosphorus-free and imparts the following properties to gasoline at low treating levels and low cost:

- Carburetor Detergency
- Rust Prevention
- Carburetor Icing Protection
- Reduced Maintenance Cost
- Aids Emission Control

DUPONT

Petroleum Chemicals

E. I. du Pont de Nemours & Co. (Inc.)
Petroleum Chemicals Division
Wilmington, Delaware 19898

APPLICATION - DMA-53 is a versatile multifunctional additive which provides excellent carburetor detergency, anti-icing and rust protection.

CONCENTRATION - To obtain all of the benefits described above, concentrations in the range of 3 to 9 lb/1000 bbl (12-36 ppm) are recommended.

PROPERTIES - (Typical)

Specific Gravity, 60/60F (16/16C)	0.92
API Gravity, 60F (16C)	23.0
Pounds/Gallon, 60F (16C)	7.63
Flash Point, PMCC	35F (2C)
Pour Point	-60F (-51C)
Nitrogen, wt %	4.1

Viscosity:	Temperature	SUS	cSt
	0F (-18C)	1370	298
	32F (0C)	500	108
	100F (38C)	109	23

ADDITION - Either batchwise or continuously as a concentrate or in a stock solution.

PRECAUTIONS IN HANDLING - Flammable. Causes irritation. It contains methanol and may be fatal or cause blindness if swallowed. Avoid contact with eyes, skin and clothing. Avoid breathing vapor. Keep container closed. Use with adequate ventilation. Wash thoroughly after handling. Keep away from heat, sparks and open flame. In case of fire, use water spray, foam, dry chemical or CO_2.

FIRST AID - In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. If swallowed induce vomiting. Call a physician immediately. Wash clothing before reuse.

RES/eaa
10/17/80

Appendix 3

DMA-53/DCI-11 BLEND

PHYSICAL PROPERTIES

Specific Gravity 60/60°F (15.6°C)	0.931
Density lb/gal 60°F (15.6°C)	7.75
Flash Point, PMCC, °F (°C)	64 (18)
Pour Point, °F (°C)	below -45 (-43)
Viscosity, cSt	
100°F (38°C)	30
32°F (0°C)	180
0°F(-18°C)	663

APPENDIX 5b

DU PONT DGOI-100 CORROSION INHIBITOR FOR GASOLINE-ALCOHOL FUELS

PLMR-9-85

FEBRUARY, 1985

Dr. Perry Polss, Sr. Supervisor
Petroleum Additives Division
E. I. du Pont de Nemours & Co., Inc.
Petroleum Laboratory
Wilmington, Delaware 19898

SUMMARY

DGOI-100 Corrosion Inhibitor is a multipurpose product developed by Du Pont for gasolines containing methanol and other alcohols. DGOI-100 must be used in gasoline-alcohol fuels covered by the EPA waiver granted to Du Pont on January 10, 1985. This product provides the special corrosion protection needed when alcohols are present. In addition, it provides detergency and stability properties which are desired for high quality gasolines.

DGOI-100 was effective in controlling corrosion in both laboratory bench tests and vehicle durability tests. Specimens of eight different metals including terneplate, die cast aluminum and steel showed no evidence of corrosive attack in accelerated laboratory storage tests. Metallic fuel system parts including carburetor assemblies, fuel lines and gasoline tanks were in excellent condition at the end of 50,000 mile durability tests.

The gasoline-alcohol fuel waiver by the EPA allows the use of methanol and cosolvent alcohols as blending components in unleaded gasoline. The gasoline-alcohol fuels are limited to a maximum of 5% methanol, a minimum of 2.5% cosolvent alcohols (ethanol, propanols and butanols) and a maximum of 3.7% total oxygen in the fuel. The fuels are required to meet special volatility specifications defined by the EPA.

DGOI-100

DGOI-100 Corrosion Inhibitor is a multipurpose product specially developed by Du Pont for gasoline-alcohol fuels. This product has been specified as an integral part of the gasoline-alcohol fuel waiver granted to Du Pont by EPA on January 10, 1985. A product information bulletin on DGOI-100 is provided as Table 1.

Waiver Provisions

The gasoline-alcohol fuel waiver granted to Du Pont by the EPA allows the use of methanol and cosolvent alcohols as blending components in unleaded gasoline. The gasoline-alcohol fuels are limited to a maximum of 5% methanol, a minimum of 2.5% cosolvent alcohols and a maximum of 3.7% total oxygen in the fuel. The cosolvents could consist of any one or a mixture of ethanol, propanols, GTBA, and/or butanols.

The gasoline-alcohol fuels covered by the January 10, 1985 waiver are required to meet certain volatility specifications defined by the EPA in terms of RVP, percent evaporated at 100°F, and percent evaporated at 200°F. EPA has specified a maximum evaporative index for each of the ASTM volatility classes based on the formula:

$$EI = 0.85\ RVP + 0.14\ (\text{percent evaporated at } 200°F) - 0.32\ (\text{percent evaporated at } 100°F).$$

EPA specified the use of Du Pont Corrosion Inhibitor DGOI-100 in waivered fuels at a concentration of 41.3 milligrams per liter. This is a proprietary product commercially available from Du Pont.

Waiver Literature

EPA's decision to grant a gasoline-alcohol waiver to Du Pont was announced in the Federal Register (FR 50, 12, Jan. 17, 1985). A copy is attached in Appendix A of this report.

Information on DGOI-100 was included in Section IV of the waiver application submitted to EPA by Du Pont on July 11, 1984. A copy of this section is attached as Appendix B of this report.

Performance of DGOI-100

The performance of DGOI-100 was established in an extensive series of bench and vehicle tests. The bench tests consisted of exposing specimens of metals found in automotive fuel systems to various gasoline-alcohol fuels for three months at elevated temperature. Vehicle studies included 50,000-mile tests on a group of six cars followed by complete inspections of the vehicle fuel systems at the end of each test.

DGOI-100 was effective in controlling corrosion in both laboratory bench tests and vehicle durability tests. Specimens of eight different metals including terneplate, die cast aluminum and steel showed no evidence of corrosive attack in accelerated laboratory storage tests. Metallic fuel system parts including carburetor assemblies, fuel lines and gasoline tanks were in excellent condition at the end of 50,000 mile durability tests.

Laboratory Bench Tests

A series of laboratory corrosion tests were carried out using the metals found in automotive fuel systems. Standard test coupons described in Tables 2 and 3 were used.

One set of short-term tests was carried out using a number of different test fuels, all containing 41.3 mg/L DGOI-100. The NACE Rust Test, TM-01-72, used by pipelines and others to monitor the corrosive tendencies of petroleum products, was used. While this test method was specifically developed for use with mild steel, the substitution of other metallic specimens is possible with weight change and surface inspections being used to assess any effects of the fuel.

As shown in Table 4, the change in coupon weight was very small with the maximum observed effect being within the expected variability of the test method. The specimen surfaces showed no evidence of corrosive attack. The copper specimen showed a change in color as expected in view of the anticipated passivating effect of the DGOI-100.

A set of long-term exposure tests was carried out involving storage of the metal specimens for 12 weeks at 110°F. Six different fuels all containing 41.3 mg/L DGOI-100 were used in this test program in order to cover the various alcohols being considered as cosolvents for the methanol. Actually, three sets of samples were employed in order to make weight measurements and surface examinations at 4, 8, and 12 weeks. Seventy-five percent of the fuel was changed weekly to simulate motorist practice.

The storage temperature was 110°F in order to accelerate any deterioration effects. In other fuel stability studies, one week of storage at 110°F is considered equivalent to 7 weeks at ambient conditions. Obviously, the elevated temperature accelerates the oxidation reactions yielding species which can cause corrosion. In order to provide effective corrosion protection, it is necessary to deactivate corrosive species initially present as well as provide fuel stabilization to prevent formation of additional reactants.

Weight changes of the eight metal specimens stored for 12 weeks at 110°F were small ranging from a 2.7 mg loss to a 3.6 mg gain. The copper coupons exhibited a consistent weight change for all fuels including the nonalcohol gasoline. Terneplate, a metal used widely in automotive fuel systems, exhibited only a very small change. The maximum change in coupon weight for terneplate was equivalent to a corrosion rate of 0.004 mils/year. Based on the initial plating thickness, this coating would last for 100 years. None of the coupons showed any deterioration. No pitting was observed on any of the coupons. Except for the color change of the copper coupons, appearance of the coupons at 12 weeks was equivalent to that at the start of the test. After 12 weeks of storage, all of the fuels were clear and free of precipitate. Test results are in Table 5.

In another set of tests, gasoline-alcohol fuels containing 41.3 mg/L DGOI-100 were stored for 12 weeks at 110°F without fuel replacement. When these fuels were tested in the NACE TM-01-72 test method, none of the fuels were corrosive to mild steel and all had good oxidative stability. Test results are given in Table 6.

In a complementary set of tests, the effectiveness of DGOI-100 in controlling corrosion was determined in comparison tests of (a) gasoline, (b) gasoline containing alcohols, and (c) gasoline containing alcohols and DGOI-100. These fuels were stored for 12 weeks at 110°F without fuel replacement. When these fuels were tested in the TM-01-72 test method, the fuel containing DGOI-100 was not corrosive, whereas the two control fuels were corrosive as shown in Table 7.

Corrosion tests also were conducted with two-phase systems. This was done to simulate the situation that might occur in the event a gasoline-alcohol blend is contacted by excessive amounts of water. The test involved storing eight metals -- found in automotive systems -- in a gasoline-alcohol fuel blend to which was added excess water. The excess water was sufficient to form a substantial lower phase. The metal specimens were stored in this two-phase system at 110°F (38°C) for one month. The elevated temperature served to accelerate the corrosive activity. The one-month storage was very severe since this test is typically run for only 24 hours. Table 8 describes the appearance of the test specimens and illustrates the excellent corrosion protection provided by Du Pont DGOI-100.

50,000 Mile Vehicle Tests

No fuel-related vehicle durability problems were observed in 50,000 mile tests of gasoline-alcohol fuel and nonalcohol fuel, both containing 41.3 mg/L DGOI-100. This performance is reflective of the outstanding ability of DGOI-100 in maintaining fuel system components in top operating condition. Three car makes -- 1983 Chevrolet Malibu, V-6, 3.8L; 1983 Ford Fairmont, L-4, 2.3L; and 1979 Dodge Aspen, L-6, 3.7L -- were operated on the test fuels. One of each make was driven on gasoline-alcohol fuel and one each on nonalcohol gasoline.

Critical fuel system parts were inspected at the end of the 50,000 mile tests and were found to be in excellent condition. These parts are identified in Table 9. Fuel pump and fuel filter flow performances were within specification and showed no abnormality. Compression pressures and lube oil analyses showed no evidence of unusual engine wear.

At the end of the test, a special set of tests carried out using new catalytic converters confirmed that no adverse effects on engine performance had occurred during the 50,000 miles. Exhaust emissions at 50,000 miles were equivalent to those measured at 0 miles for all six cars indicating no significant differences in carburetor metering characteristics. The exhaust emission results are reported in Table 10.

All of the fuels used in this test program contained DGOI-100 and therefore comparisons with nonadditive fuels could not be made. The fact that the vehicle performance was maintained in the "as-new" condition is all that could have been expected and this attests to the value of the product.

Several observations were made which indicated that DGOI-100 has the ability to passivate active corrosion sites. One of the fuel tanks apparently had been manufactured with an insufficient layer of terneplate on one portion of the tank. Small protrusions of steel were passivated by DGOI-100 so that no pitting, corrosion, or intergranular attack occurred. Analyses of these passivated areas indicated the presence of an iron complex of the corrosion inhibitor product.

A second indication of surface passivation by the corrosion inhibitor involved the fuel lines of several of the vehicles. Apparently, air oxidation of the fuel line interiors occurred while the lines were stored before installation on the cars. Metallographic examinations indicated the oxidation surface to be typical of that resulting from moist air conditions rather than being from aqueous liquid phase corrosion. This oxidation was arrested by the corrosion inhibitor and no pitting or liquid phase oxidation rusting was observed.

Laboratory Engine Tests

DGOI-100 has been found effective in keeping carburetors clean as reflected by tests conducted in the CRC Carburetor Cleanliness Test. Results in Table 11 show DGOI-100 is effective in reducing the weight of deposit formed in the carburetor as well as improving the appearance of the carburetor. As shown in Table 11, the presence of alcohol reduces carburetor cleanliness, but DGOI-100 in the gasoline-alcohol fuel overcomes the degradation. The additional use of 9.4 mg/L of DMA-53 gave even better carburetor performance.

Table 1

DGOI-10C

DGOI-100

CORROSION INHIBITOR

DGOI-100 . . . Under provisions of the gasoline-alcohol fuel waiver granted by EPA to Du Pont on January 10, 1985, DGOI-100 at 41.3 mg/L is required in waivered fuels. The performance and effectiveness of DGOI-100 were established in laboratory and vehicle tests as cited in the waiver application.

DUPONT

Petroleum Chemicals
Wilmington, DE 19898

TAP/eaa
1/22/85

APPLICATION - Provides antirust, stability and detergency properties for gasoline/oxygenate blends.

CONCENTRATION - 14.5 lb/1000 bbl (41.3 mg/L) in finished gasoline/oxygenate blends.

PROPERTIES - (Typical)

Physical Form			Clear, brown liquid
Specific Gravity, 60/60F (16/16C)			0.94
Density, 60F (16C), lb/gal			7.85
Flash Point, PMCC			78F (26C)
Ash Content, wt %			0.02
Solubility in Hydrocarbons			miscible
Viscosity:	Temperature	SUS	cSt
	0F (-18C)	8176	1776
	32F (0C)	1453	315
	100F (38C)	142	30

PRECAUTIONS IN HANDLING - Danger! Causes burns (as defined by D.O.T. Skin Corrosivity Test). Flammable liquid. May cause allergic skin reaction. Contains methanol and may be fatal or cause blindness if swallowed. Vapor harmful. Cannot be made non-poisonous. Do not get in eyes, on skin, on clothing. Avoid breathing vapor. Keep container closed. Use with adequate ventilation. Wash thoroughly after handling. Keep away from heat, sparks and flame.

In case of fire, use water spray, foam, dry chemical or CO_2.

FIRST AID - In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes while removing clothing and shoes. Call a physician. Wash clothing before reuse.

Table 2

METAL TEST SPECIMENS

Specimens Obtained from the Meta-Spec Company

	Inches			Mils	Grams
Coupons	Length	Width	Thickness	Plating Thickness	Weight
Terneplate	2	0.5	0.030	0.4 Nominal	3.9
Tin Plate	2	0.5	0.010	0.015 Nominal	1.2
Cadmium Plate	2	0.5	0.040	3.0 Minimum	7.8
Zinc Pot Metal 903	2	0.5	0.125	—	13.3
Admiralty Brass	2	0.5	0.0625	—	8.6
Copper	2	0.5	0.0625	—	8.4
Aluminum Alloy 309	2	0.5	0.125	—	5.8
Steel - 1010 Grade	2	0.5	0.0625	—	7.4

Table 3

METAL SPECIMEN ANALYSES

Weight Percent

Terneplate Hot-Dipped Terne Sheet on SAE 1010 Steel

Pb	Sn	Sb	Bi	Cu	Fe
90	9.2	0.3	Trace	0.02	Trace

Tin Plate Electrolytic-Coated Tin Plate on SAE 1010 Steel

Sn	P	S
99.9	0.006	0.03

Cadmium Plate Electrodeposited Cadmium Plate on SAE 1010 Steel

Cd	Ag	Cu	Pb	Sn	Zn	Other Remaining
99.9	0.01	0.01	0.02	0.01	0.03	

Zinc Pot Metal Zinc Base Die Cast Alloy Zimak 3

Zn	Al	Mg	Cu	Pb	Cd
95.96	3.9	0.04	0.10	Trace	Trace

Admiralty Brass Admiralty Brass CDA 443

Cu	Sn	Pb	Fe	As	Zn
71.20	1.17	0.01	0.01	0.07	Remaining

Copper Copper Alloy 110 Electrolytic

Cu	Ag
99.90	Remaining

Aluminum Aluminum Foundry Alloy SAE 329

Al	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn
87.60	3.0	0.70	0.21	0.70	0.40	6.1	0.20	1.0

Steel Steel SAE 1010

Fe	C	Mn	P	S
99.38	0.09	0.50	0.02	0.01

Table 4

NACE RUST TEST RESULTS

"Fresh" Fuels
All Fuels Contained 41.3 mg/L DGOI-100

	Coupon Weight Change, mg					
	Nonalcohol Gasoline	5 M+ 2.5 M_xAl	5M+ 4.2 M_xAl	5 M+ 3.2 E	5 M+ 4.1 P	5 M+ 5.0 B
Terneplate	−0.1, −0.2	0.0	−0.2	−0.1, −0.3	−0.1	−0.2
Tin Plate	0.0, −0.1	0.0	0.0	+0.1, 0.0	+0.1	+0.1
Cadmium Plate	−0.1, −0.1	−0.1	−0.1	+0.1, +0.1	+0.1	0.0
Zinc Pot Metal	−0.2, 0.0	−0.1	−0.2	−0.2, −0.2	−0.1	+0.1
Admiralty Brass	−0.1, −0.1	0.0	0.0	0.0, −0.1	−0.1	0.0
Copper	−0.2, 0.0	−0.2	−0.2	−0.3, −0.3	−0.4	−0.1
Die-Cast Aluminum	0.0, −0.1	0.0	−0.2	0.0, −0.2	−0.1	+0.1
1010 Grade Steel	−0.1, −0.2	−0.1	−0.2	+0.1, −0.1	−0.1	0.0

5M = 5% methanol; 2.5M_xAl = 2.5% mixture of ethanol (E), propanols (P) and butanols (B), etc.

Table 5

FUEL STORAGE TESTS

110 F - 12 Weeks
Replaced 75% of Fuel Each Week

	Coupon Weight Change, mg(1)					
	Nonalcohol Gasoline	5 M+ 2.5 M_xAl	5M+ 4.2 M_xAl	5 M+ 3.2 E	5 M+ 4.1 P	5 M+ 5.0 B
Terneplate	-0.10	-0.20	-0.25	0.00	-0.05	0.00
Tin Plate	0.00	+0.05	0.00	+0.10	+0.05	+0.10
Cadmium Plate	+0.05	-0.15	-0.35	-2.70	+0.20	-0.30
Zinc Pot Metal	-0.30	-0.10	-0.10	0.00	+0.25	+3.65
Admiralty Brass	-0.10	-0.65	-0.60	-0.35	-0.15	-0.35
Copper	-1.15	-1.05	-1.40	-1.90	-0.95	-0.75
Die-Cast Aluminum	+0.15	+0.10	0.00	+1.00	+0.25	+0.20
1010 Grade Steel	+0.15	-0.10	-0.70	+0.05	+0.10	+0.20

(1)Average of Duplicate Determinations

o All fuels clear after 12 weeks

5M = 5% methanol; 2.5M_xAl = 2.5% mixture of ethanol (E), propanols (P) and butanols (B), etc.

Table 6

STORAGE STABILITY OF TEST FUELS

Fuels Containing 41.3 mg/L DCOI-100 Stored 12 Weeks @ 110 F(1)
No Fuel Exchange
No Test Specimens in Fuel During Storage

Fuel Blends				Performance After 12-Week Storage		
		Cosolvent				
Base Gasoline	MeOH, V%	Type	V%	TM-01-72 NACE Rust Rating	ASTM D525 Induction Period, Minutes(3)	ASTM D381 Existent Gum-Washed, mg/100 mL(4)
High Aromatic	—	—	—	B+4(2)	1440+	1.1
High Aromatic	5	M_xAl	2.5	A 0	1440+	1.7
High Aromatic	5	M_xAl	4.2	A 0	1440+	1.7
High Aromatic	5	Ethanol	3.2	A 0	1440+	2.9
High Aromatic	5	Propanol	4.1	A 0	1440+	3.0
High Aromatic	5	Butanol	5.0	A 0	1440+	1.3

(1) 1 Week storage @ 110 F is equivalent to 7 weeks @ 80 F;
12 weeks @ 110 F is equivalent to 84 weeks (1.6 years) @ 80 F

(2) Letter (B or A) represents qualitative rating; number (4 or 0) shows proportion of test surface rusted

(3) ASTM D439 minimum = 240 minutes

(4) ASTM D439 maximum = 5 mg/100 mL

EFFECT OF DGOI-100 ON THE CORROSION TENDENCY OF FUELS STORED FOR EXTENDED PERIODS

Fuel Stored for 12 Weeks at 110°F
No Metal Coupons in Stored Fuels
NACE TM-01-72 Test Method (Steel)

	NACE Rust Test Rating		
Weeks @ 110°F:	0	4	12
Gasoline	E (90)	E (90)	E (80)
Gasoline + 5M + $4.2M_xAl$	B (5)	C (30)	D (60)
Gasoline + 5M + $4.2M_xAl$ + 41.3 mg/L DGOI-100	A (0)	A (0)	A (0)

( ) % Rust

STATIC TWO-PHASE CORROSION TEST OF GASOLINE-ALCOHOL FUELS WITH ADDED WATER

(4 Weeks Storage at 110°F)

DGOI-100 Conc = 41.3 mg/L

	HC Phase		Water Phase	
	Control	DGOI-100	Control	DGOI-100
Terneplate	Clear	Clear	Etched	Clear
Tin Plate	Clear	Clear	Lt Discolor	Clear
Cadmium Plate	Clear	Clear	Pitted	Etched
Zinc Pot Metal	Clear	Clear	Pitted	Etched
Admiralty Brass	Lt Discolor	Clear	Hvy Discolor	Clear
Copper	Hvy Discolor	Lt Discolor	Etched	Lt Discolor
Aluminum	Clear	Clear	Etched	Clear
1010 Grade Steel	Clear	Clear	Pitted	Clear

Table 9

CRITICAL FUEL SYSTEM COMPONENTS EXAMINED AT END OF 50,000-MILE DURABILITY TEST

CARBURETOR

- Fuel Bowl Surfaces
- Float
- Needle Tip
- Accelerator Pump Seal

FUEL PUMP

- Diaphragm
- Check Valves
- Seal

GAS TANK

- Internal Terneplate Surfaces
- Gas Line
- Canister Vent Line

Table 10

EXHAUST EMISSIONS WITH NEW CONVERTERS

Fuel: Indolene

Nonalcohol Gasoline Cars	Start of Test - g/mi.			End of Test - g/mi.		
	HC	CO	NO_x	HC	CO	NO_x
1983 Chevrolet	0.2	1.1	1.0	0.2	0.8	0.6
1983 Ford	0.3	2.9	1.1	0.2	0.4	0.9
1979 Dodge	0.6	7.2	1.3	0.5	6.8	1.4
Gasoline-Alcohol Fuel Cars						
1983 Chevrolet	0.3	1.6	0.8	0.2	0.7	0.8
1983 Ford	0.4	1.9	1.2	0.4	1.7	0.8
1979 Dodge	0.9	18.2	1.1	1.6	26.1	1.0

EVALUATION OF DGOI-100 IN THE MODIFIED CRC CARBURETOR CLEANLINESS TEST

Base Fuel = Phillips J

Additive, mg/L	Deposit	
	Rating (10=Clean)	Weight (mg)
None	6.7	16.6
Alcohols (5M + 4.2M_xAl)	5.0	21.8
Alcohols + 41.3 mg/L DGOI-100	6.9	4.6
Alcohols + 41.3 mg/L DGOI-100 + 9.4 mg/L DMA-53	7.7	0.8

ENVIRONMENTAL PROTECTION AGENCY

[FRL-2746-1]

Fuels and Fuel Additives; Waiver Decision; E.I. Du Pont de Nemours & Co., Inc.

AGENCY: Environmental Protection Agency (EPA)

ACTION: Notice.

SUMMARY: Pursuant to section 211(f) of the Clean Air Act, the Administrator of EPA is conditionally granting an application for a fuel waiver involving methanol and cosolvent alcohols submitted by E. I. DuPont de Nemours & Company, Inc. (DuPont).

ADDRESSES: Copies of documents relevant to this waiver application, including the Administrator's decision document, are available for inspection in public docket EN-84-06 at the Central Docket Section (LE-131) of the Environmental Protection Agency, Gallery I-West Tower, 401 M Street, SW., Washington, D.C. 20460, (202) 382-7548, between the hours of 8:00 a.m. and 4:00 P.M. As provided in 40 CFR Part 2, a reasonable fee may be charged for copying services.

FOR FURTHER INFORMATION CONTACT: Sylvia I. Correa, Attorney-Advisor, Fuels Branch, Field Operations and Support Division (EN-397F), U.S. Environmental Protection Agency, 401 M Street, SW, Washington, D.C. 20460, (202) 382-2635.

SUPPLEMENTARY INFORMATION: Section 211(f)(1) of the Clean Air Act (Act), 42 U.S.C. 7545(f)(1), generally prohibits the introduction into commerce of certain new automotive fuels and fuel additives. Section 211(f)(4) of the Act provides that the Administrator of the EPA, upon application by a fuel or fuel additive manufacturer, may waive the prohibitions established under section 211(f) if the Administrator determines that the applicant has established that such fuel or fuel additives will not cause any vehicle to fail to meet applicable emissions standards.

DuPont has submitted a waiver application under section 211(f) of the Act requesting that EPA grant a waiver for introduction into commerce of a gasoline-alcohol fuel. The gasoline-alcohol fuel is composed of a maximum of 3.7 weight percent fuel oxygen with a maximum of 5.0 percent by volume methanol and a minimum of 2.5 percent by volume cosolvent alcohol(s) with a proprietary corrosion inhibitor, or its equivalent. The cosolvent(s) is any one or a mixture of ethanol, propanols, or butanols, including gasoline grade tertiary butyl alcohol (GTBA).

The waiver application that the gasoline-alcohol fuel conform to American Society for Testing & Materials (ASTM) D439, including the June 1984 proposed revision and any subsequent revisions. See 49 FR 31845 (August 9, 1984).

For reasons specified in the decision document (available as described above), I have decided to conditionally grant DuPont's waiver application provided the gasoline-alcohol fuel is produced in accordance with an evaporative index (EI) volatility standard and the corrosion inhibitor is restricted to DuPont's DCOI-100. Production of the fuel in accordance with only the ASTM D439 requirement specified by DuPont would require a denial of the application. This decision is based on the determination that DuPont has demonstrated that the gasoline-alcohol fuel, when used as specified in the decision document, will not cause or contribute to a failure of any 1975 or subsequent model year vehicle or engine to comply with the emission standards with respect to which it was certified under section 206 of the Act. Thus, the waiver request is granted provided the following conditions are met:

(1) The final fuel consists of a maximum of 5.0 volume percent methanol, a minimum of 2.5 volume percent cosolvent (ethanol, propanols, GTBA, and/or butanols) in unleaded gasoline;

(2) A maximum concentration of up to 3.7 weight percent oxygen in the final fuel is observed;

(3) DuPont's proprietary corrosion inhibitor formulation, DCOI-100, is blended in the final fuel at 41.3 milligrams per liter (mg/l);

(4) The final fuel meets ASTM D439-83 Standard Specifications for Automotive Gasoline (a copy of which is in the Docket), with the qualification that Test Method D323 for RVP be replaced by the test method attached hereto as Appendix B;

(5) The finished gasoline-alcohol fuel meets the fuel volatility specifications of the Evaporative Index as follows: $EI = 0.85\ RVP + 0.14$ (percent evaporated at 200° F) $- 0.32$ (percent evaporated at 100° F). EI is not to exceed 12.0 psi in ASTM Class A areas, 12.9 psi in Class B areas, 13.1 psi in Class C areas, 14.6 psi in Class D areas, and 15.0 psi in Class E areas;

(6) The final fuel must meet the maximum temperature for phase separation as specified in Appendix C using the test method for water tolerance contained therein;

(7) The fuel manufacturer takes all reasonable precautions to ensure that the finished fuel is not used as a base gasoline to which other oxygenated materials are added;

(8) Specifications for alcohol purity attached to the decision document as Appendix D are met.

EPA has determined that this action does not meet any of the criteria for classification as a major rule under Executive Order 12291. Therefore, no regulatory impact analysis is required.

This action is not a "rule" as defined in the Regulatory Flexibility Act, 5 U.S.C. 601(2), because EPA has not published a Notice of Proposed Rulemaking under the Administrative Procedure Act, 5 U.S.C. 553(b), or other law. Therefore, EPA has not prepared a supporting regulatory flexibility analysis addressing the impact of this action on small entities.

This is a final Agency action of national applicability. Jurisdiction to review this action lies exclusively in the U.S. Court of Appeals for the District of Columbia Circuit. Under section 307(b)(1) of the Act, judicial review of this action is available only by the filing of a petition for review in the U.S. Court of Appeals for the District of Columbia Circuit within 60 days of January 17, 1985. Under section 307(b)(2) of the Act, today's action may not be challenged later in a separate judicial proceeding brought by the Agency to enforce the statutory prohibitions.

Dated January 10, 1985.

Lee M. Thomas,
Acting Administrator.

[FR Doc. 85-1351 Filed 1-16-85; 8:45 am]

BILLING CODE 6560-50-M

SECTION IV

CORROSION INHIBITOR FORMULATION

A commercially available Du Pont corrosion inhibitor formulation, DGOI-100, has been specified for use in gasoline-alcohol fuels covered by this waiver application. DGOI-100 is used at a concentration of 41.3 mg/liter in finished gasoline-alcohol fuels. A product sheet for DGOI-100 is included as Attachment IV-1.

The performance of DGOI-100 was established in an extensive series of bench and vehicle tests. The bench tests consisted of exposing specimens of metals found in automotive fuel systems to various gasoline-alcohol fuels for three months at elevated temperature. Analytical inspection tests were carried out on these specimens periodically throughout the test period. Vehicle studies included 50,000-mile tests on a group of six cars, followed by complete inspection of the vehicle fuel systems at the end of each test. Exhaust emission tests were performed at the beginning and end of each test to establish the efficacy of the corrosion inhibitor in helping to maintain the performance of the emission control systems. In addition to these tests directed specifically to the corrosion inhibition characteristics of the fuel blends, a wide variety of bench tests as well as a number of additional vehicle tests were carried out to evaluate the effect of the blends on elastomer and plastic materials.

Under the provisions of this waiver application, an equivalent corrosion inhibitor formulation may be used in place of the Du Pont formulation. In order to establish this equivalency, based on present understanding of test methodology, it would be necessary to carry out the same type of tests used to establish the efficacy of the Du Pont product in the gasoline-alcohol compositions covered by this waiver application. These tests would include both bench and vehicle studies conducted in connection with this waiver application. Perhaps at some future date, ASTM or some other organization responsible for industry acceptance tests will develop generally accepted corrosion performance standards for gasoline-oxygenate blends that can be used to qualify corrosion inhibitor formulations. At present, such standards have not been established.

APPENDIX 6

Indian Institute of Petroleum

Optimization of operating conditions of Glow Plug assisted neat Methanol fuelled direct injection Kirloskar AV1 Diesel Engine for Lubrication and Wear Studies.

Report No. EL-0985 May, 1985

Report by

Dinesh Kumar
C.S. Nawani
B.P. Pundir

Approved by

S. Singhal.

INTRODUCTION

For lubrication and wear studies of methanol fuelled direct injection diesel engines and to evaluate the performance of different crank case lubricating oils, the glow plug assisted methanol engine was selected. Lubrication study group of Engines laboratory suggested that engine should be capable of running satisfactorily at high speed, high load but with low coolent temperature. The coolent out let temperature of 40±2°C was suggested. The earlier optimization work, related mostly to the rated speed and load conditions as obtained with diesel i.e. 3.75 KW at 1500 rpm(1,2) Further to increase the life of glow plug it is to be operated at a low wattage.

EXPERIMENTAL SET UP/CONDITIONS

Test engine specifications and the details of experimental set up are given in an earlier report(1). A glow plug adoptor for varying the glow plug projection in the combustion chamber was fabricated. (FIG.1) A special glow plug(FIG.2) with built in thermocouple was used to measure the glow plug tip temperature. The piezo eletric pressure transducer was mounted flush with combustion chamber. The pressure time history was continiously observed on the oscilloscope.

It was desired that the engine load and speed for a satisfactory operation of the engine are selected at a fix value of injector pop-off pressure, injection advance, glow plug voltage and the coolent temperature as given in Table 1. Test were conducted with two fuel injection pump elements of 7 mm (standard) and 8 mm dia.

TABLE 1

Coolent Temperature	40 ± 2 °C
Injector opening pressure	18.6 MPa,
Injection Advnce	30° btdc
Glow plug voltage	11.5-12V (110-120W)

RESULTS AND DISCUSSION

Intially experiments were conducted with 7.0 mm F.I.P. element and 10.0 mm glow plug projection. At 1600 rpm, 4.8 kW out put engine was stable but fuel rack was set at its maximum limit. Due to this governer operating became ineffective and it was not possible to maintain engine load and speed conditions stable for long period.

To overcome the fuel delivery limitations injection pump element was changed to 8 mm dia. The results are given in Table -2 with different glow plug projections.

It is observed that brake specific energy consumption decreases and glow plug temperature increases with decrease in glow plug projection, at a given glow plug energy. (110-120 W). At 15 mm glow plug projection, 100 watt energy was not sufficient for a stable combustion and late combustion was observed even at 4.8 KW. It also means that to obtain an stable engine operation a higher glow plug energy is required with increase in the glow plug projection in the combustion chamber. At 5.0 mm glow plug projection a minimum 4.2 KW output at 1600 rpm is required for stable engine combustion. The glow plug temperature at this condition was 1005 ± 3 °C. At this condition ~~For~~ glow plug temperature lower than 1000 °C, combustion became unstable.

The brake energy specific consumption at 1600 rpm 4.2 KW is 11.6 MJ/KW-hr. Which is comparable to diesel at rated load and speed. Engine operation was observed over a period of 2 hrs and periodic performance data is given in Table -3, showing thereby that engine operation remains fairly stable at glow plug energy of (110-120 W).

CONCLUSIONS

- The glow plug energy requirement decreases with decrease in glow plug projection in to the combustion chamber.
- For a fixed glow plug energy input and engine load, the glow plug temperature increases with decrease in glow plug projection
- The test engine should develop minimum 4.2 KW at 1600 rpm for proper combustion at 110 W energy input to glow plug. For this 5 mm glow plug projection with 8.0 mm F.I.P. element dia is recommended,

REFERENCES:

1 Dinesh Kumar and B.P. Pundir, "A Methanol Fuelled D.I.Diesel Engine." 8th National Conference on I.C. Engines and Combustion Trivandrum, 1983.

2 Dinesh Kumar and B.P. Pundir, " Combustion and Performance Characteristics of a Methanol Fuelled D.I. Diesel Engine." VI International Symposium on Alcohol fuels Technology, OTTAWA, CANADA, May, 1984.

TABLE 2 EFFECT OF GLOW PLUG PROJECTION ON ENGINE PERFORMANCE

Fuel :- 99%Methanol + 1% Caster oil

Injection Advance:-30° btd C

Injector Opening Pressure-18.6 MPa.

FUEL - DIESEL

Injection Advance - 27° btdC.

Injector Opening pressure -18.6 MPa.

S.N.	R.P.M	F.I.P element dia mm	B.HP KW.	Brake specific energy consumption MJ/KW-hr	Glow Plug Projection mm	Glow Plug Voltage V	Glow Plug AMP	Glow plug Wattage Watt	Net B.S.E.C MJ/KW-hr	Water outlet temp. °C	Oil Temp °C	Exhaust temp. °C	Glow Plug Temp °C	Remarks
	METHANOL													
1.	1600	7.0	4.9	11.4	10	11.0	9.2	100	11.6	40	60	490	1016	
2.	1600	8.0	4.8	11.0	5	11.5	9.5	110	11.25	38	58	460	1030	
3.	1600	8.0	4.8	11.5	10	11.5	9.5	110	11.80	38	62	490	1030	
4.	1600	8.0	4.8	-	15	11.5	8.5	98	-	38	55	510	1000	Late combustion
5.	1600	8.0	4.2	11.6	5	11.5	9.8	113	11.9	38	60	430	1007	Smoke Hartridge Unit/Bosch Unit-8/0.8
6.	1600	8.0	4.2	12.80	10	11.5	9.5	110	13.1	36	62	505	988	± 15 rpm variation
	DIESEL													
	1500	7.0	3.75	11.6	-	-	-	-	-	80	65	470	-	Rated condition Smoke Hartridge Unit/ Bosch no-80/5.5

TABLE -3 REPEATABILITY OF TEST

FUEL-METHANOL

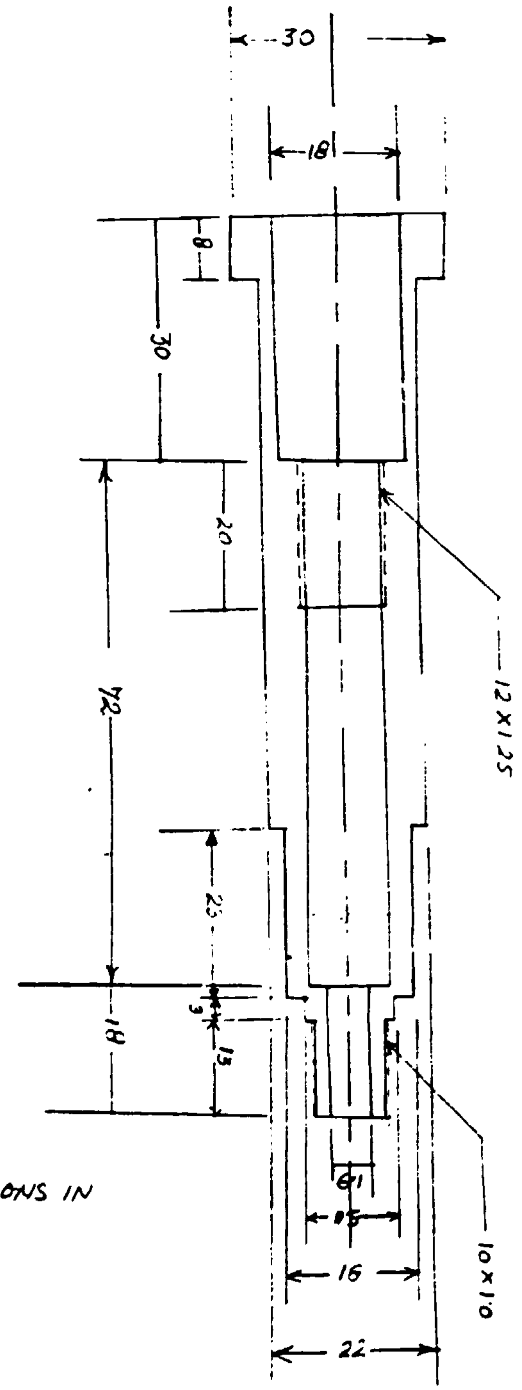
GLOW PLUG PROJECTION - 5.0 mm.

INJECTION ADVANCE -30° btdC.

INJECTOR OPENING PRESSURE -18.6 MPa

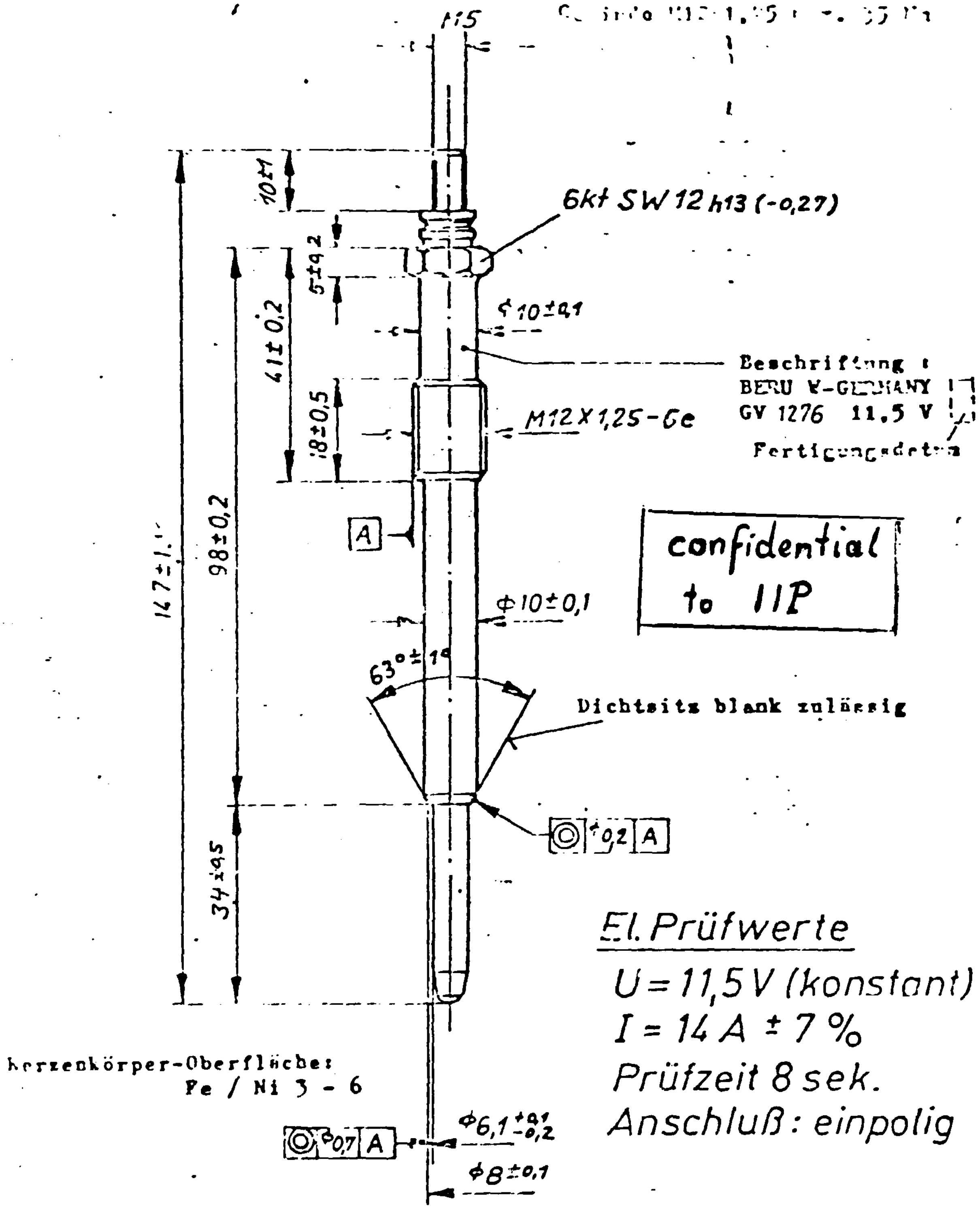
F.I.P. ELEMENT DIA -8.0 mm.

S.NO.	R.P.M.	B.H.P. KW	Brake specificati energy comsumptionMj/Kw -hr	G.P. Voltage V	G.P. Current AMP	Glow Plug Wattage	Net B.S.E.C MJ/Kw -hr	Water outlet temp. °C	Oil Temp. °C	Exhaust Temp. °C	Glow Plug Temp. °C
1.	1610	4.2	11.4	12.0	10.5	125	11.75	40±2	55	440	1029
2.	1608	4.2	11.3	12.0	10.5	125	11.64	40±2	58	430	1018
3.	1600	4.0	11.9	12.25	10.6	130	12.25	40±2	60	410	1016
4.	1600	4.2	11.3	12.0	10.5	125	11.64	40±2	62	420	1037
5.	1600	4.2	11.3	12.0	10.5	125	11.64	40±2	63	420	1038
6.	1600	4.2	11.4	12.0	10.5	125	11.75	40±	65	425	1040



DIMENSIONS IN
MM

FIG-1 GLOW PLUG ADAPTER



confidential
to IIP

El. Prüfwerte

U = 11,5 V (konstant)
I = 14 A ± 7 %
Prüfzeit 8 sek.
Anschluß: einpolig

7. Nov. 1980

Fig-2 .. **GLOW PLUG**

1980	Tag	Name	Werknorm	Werkstoff
Gezeichnet	6.11.			
Geprüft				
Normgeprüft				

Nr.	Art der Änderung	Tag	Name

Maßstab
1:1

BERU
LUDWIGSBURG

Benennung
SR-10-Stabglühkerze
GV 1276

Z.Nr. 14 031 - A
Ersatz für
Ersetzt durch

APPENDIX 7

INDIAN INSTITUTE OF PETROLEUM DEHRADUN
ENGINES LABORATORY

COMPARATIVE ASSESSMENT OF CORROSION INHIBITORS FOR METHANOL FUEL USING DIFFERENT FUEL SYSTEM METALS/ALLOYS

Report No. EL 1085 May 1985

Report by:

A. Jayaraman

Mukesh Gupta

Approved by:

Head,
Petroleum Products Application Div.

1.0 OBJECTIVE:

Corrosion control of Engine Fuel System metals/ alloys in contact with methanol and methanol blended gasoline.

2.0 INTRODUCTION:

The anodic character of different metals was determined by using Electrode Potential Measurement method. An Electro Chemical Three Point Method (TPM) introduced by Barnartt (1,2) has been used as technique for comparative evaluation of different corrosion inhibitors.

3.0 TECHNIQUE:

The steady state electrode potentials of different engine metals and alloys in methanol at 14°C were measured with respect to saturated calomel electrode (S.C.E.) as a refrence electrode. The electrolytic connection between S.C.E. and methanol is made by using methanol bridge to avoid contamination of test methanol by chloride ions.

3.1 Three Point Polarization Method.

It gives corrosion rate of test metal in the corrosive medium at the time of measurement in terms of current density. The method involves use of three electrodes, one of which is the test electrode. Cathodic perturbation potentials are applied to the test electrode in the sequence of $-\Delta E$, $-2\Delta E$ and $-3\Delta E$ (where ΔE value is either 20 or 30 mv) and the corresponding steady state current values flowing through the test electrode are measured.

The corrosion current density is calculated from the measured values of $I_{-\Delta E}$, $I_{-2\Delta E}$ and $I_{-3\Delta E}$ using the following equations(3):- corrosion current Density IC ($\mu a/cm^2$)

$$= \frac{I_{-\Delta E}}{A\,(4r_2 - 3r_1^2)}$$

where

$$r_1 = \frac{I_{-2\Delta E}}{I_{-\Delta E}} \quad ; \quad r_2 = \frac{I_{-3\Delta E}}{I_{-\Delta E}}$$

and A is the area of test electrode in Cm^2.

The corrosion current densities of metal in the corrosive medium are measured for systems without and with different dosage levels of corrosion inhibitors. The effectiveness of corrosion inhibitor is expressed as the %age efficiency from the following relationship:-

Inhibitor Efficiency at a specific dosage level, % $= \dfrac{Ic - I_{c'}}{IC} \times 100$

Where I_c and $I_{c'}$ are the corrosion current Densities of the test metal in the absence and in the presence of specific dosage level of inhibitor respectively.

TEST MEDIUM	: Methanol + 0.002 M Nacl + 1% Vol.Water.
Temperature	: 35 ± 0.1°C
Inhibitor tested	: A, B, C.
Test Time	: 2 Hours.

4.0 INHIBITORS EVALUATED

INHIBITOR A: It is a clear, dark amber liquid containing only C, H, O in its formulation.

Density @ 60°F (16°C) g/ml	0.93
Pour Point, °C	-51
Flash Point, °C (°F)	11 (34)
Ash Content % Wt.	0.0
Solubility in Hydrocarbons	Completely miscible.
Viscosity, Cst @	
0°C	456
99°C	8

INHIBITOR B: It is a clear liquid of amine salts of alkyl acid phosphate.

INHIBITOR C: No Details are available.

5.0 RESULTS AND DISCUSSION:

Steady state single electrode potential data given in Table 1 indicated that lead is severely attacked with methanol and the trend for other metals viz. aluminium alloy, zemak, brass is on lower side. This showed that these metals/alloys require protection against corrosion when used with methanol. However, the specimens were taken from engines itself. Further studies were taken up with different types of corrosion inhibitors (A, B, C) at different concentration levels and with different test sample using THREE POINT POLARIZATION METHOD. The results are given in Table 2., indicated that in case of mild steel at lower concentration of inhibitor (20ppm) inhibitor C showed higher efficiency (Fig.1). However, the corrosion density of mild steel and copper are very close but brass has a very high value of 3.006 $\mu A/CM^2$. Similarly, in case of brass, inhibitor C does not result in higher inhibitor efficiency evaluated at different concentrations.

6.0 FUTURE WORK:

Comparative evaluations of different corrosion inhibitors will be done with different metal specimen using different levels of inhibitors. Two more well proven corrosion inhibitors are in the process of procurement from M/s.DUPONT and similar work will be done on them. Based upon the laboratory experience further studies will be carried out on 2 stroke engine test bench running on 90M methanol fuel. The data thus obtained will enable to decide about the inhibitors to be used in field studies.

REFERENCES:

1. Barartt, S., Electrochem Acta, Vol. 15, P.1313 (1970)

2. Barnartt, S., Corrosion, 27(11), p.467 (1971).

3. Danielson, M.J. Corrosion, Vol. 38, No.11; p 580(1982).

TABLE 1

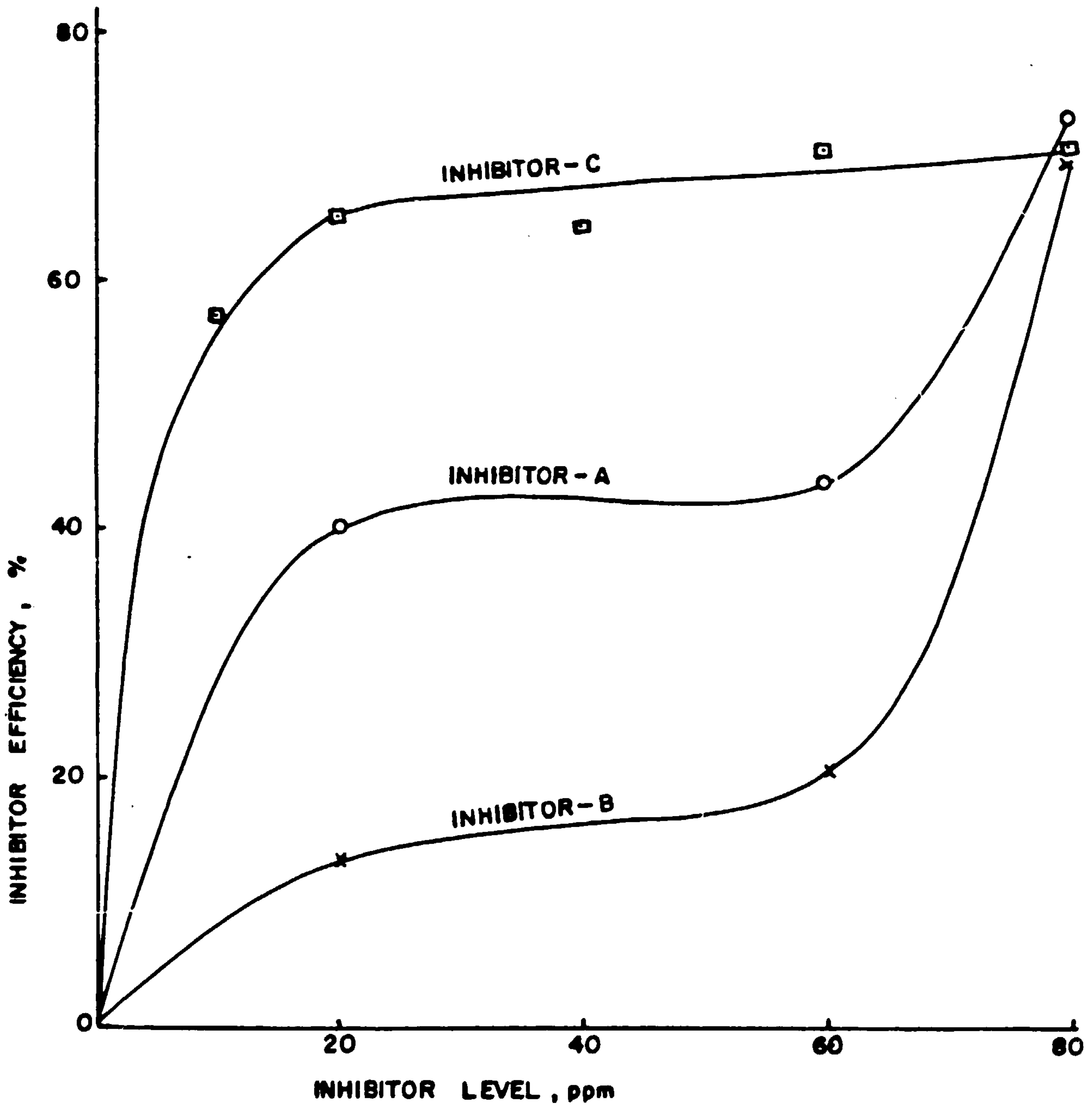
STEADY STATE SINGLE ELECTRODE POTENTIAL IN METHANOL AT 14°C

SPECIMEN	POTENTIAL, VOLTS Vs S.C.E.
LEAD	- 0.510
ALUMINIUM ALLOY	- 0.460
ZEAK	- 0.420
BRASS	- 0.190
MILD STEEL	- 0.055

TABLE 2: INHIBITORS EFFECTIVENESS

METAL/ALLOY TESTED	CORROSION DENSITY, $\mu A/Cm^2$ (BLANK)	INHIBITOR EFFICIENCY (%) OF											
		INHIBITOR A @ Conc, PPM				INHIBITOR B @ Conc; PPM				INHIBITOR C @ Conc; PPM			
		20	40	60	80	20	40	60	80	20	40	60	80
Mild Steel	1.539	40	-	44.5	73	13.5	-	20.5	69.5	65.2	64.1	69.7	69.6
Brass	3.006									22.9	33.7	-	28.45
Copper	1.755												

RS



MILD STEEL IN METHANOL HAVING 0·002 M NaCl & 1 Vol.% WATER @ 35 ± 0·1°C (THREE POINT POLARIZATION METHOD)

APPENDIX 8

INDIAN INSTITUTE OF PETROLEUM, DEHRADUN.
Engines Laboratory.

CLEANLINESS AND WEAR OF THE METHANOL TWO-STROKE ENGINE.

Report No. EL 1285 May, 1985

Prepared by:

Mukesh Gupta.

Approved by:

Head,
Petroleum Products ApplicationDi

1. OBJECTIVE:

To study the wear and deposit forming characteristics of Methanol fuelled Engine and compare the whole system with that of gasoline.

2.0 TEST TECHNIQUE:

The test engine was modified (see Annex.3) and the methanol fuel used was 90% Methanol + 10% gasoline. The engine was fitted with new components before starting the test and the measurements were taken. The new components were run-in as per scheduel given in Appendix(I), which is of 8 hrs duration and the following combinations were used:

Gasoline fuel + 4% OIL A (see data sheet)
Methanol fuel + 2.5% OIL C (see data sheet)

After the completion of running-in period, the engine was opened and ring wear was taken for each test and piston was observed for seizure marks. The run-in assembly was put back and following tests were run as follows.

2.1 Wear And Deposit Test:

The test procedure is so devised that it can give indicative results of oil, fuel behaviour. The test duration is completed as per schedule (Appendix I) of 22 hrs operation. This was all gasoline run-in assembly and subsequently switching over to methanol fuel with different oils as follows:

Gasoline fuel + 3%, Oil A
Methanol fuel + 2%, Oil B, C, and C + Additive v

2.2 Wear And Deposit Test:

After studying the engine and lubricant behaviour during 22 hrs. engine test, long duration, 160 hou cyclic test were conducted. The main objective was to check the two systems viz. gasoline and methanol fuels. The test were conducted as per cyclic test procedure given in Appendix (I).,with different fuels, oils as follows:-

gasoline fuel + 3% Oil A
methanol fuel + 1.5% (Oil C + Additive v)

3.0 RESULTS AND DISCUSSION:

3.1 Wear and Deposit Test (22hrs.):

Comparative wear and deposit 22hrs test data indicated that piston deposits in general are more with methanol fuel. Oil B indicated cleaner piston skirt, under skirt, ring land, as compared to oil C. The oil B, however, resulted in the severe ring sticking, which shows that it cannot be used for long duration studies. Oil B also showed some piston seizure on antithrust side.

Piston ring wear during test is almost double with methanol fuel using oil C (Oil C + additive) as compared to gasoline. However, Oil C showed no ring sticking. This proves that (Oil C + additive) at lower concentration can be used for long duration studies.

3.2 The test result data given in table 2 (after 160hrs.) indicated that methanol engine has given more piston skirt, under skirt deposits, top ring and cylinder wear. However, methanol fuel operation has reduced the piston Under crown, exhaust port blocking considerably. The effect of engine operating duration on top ring wear shown in Fig (1) indicated that the running-in wear and test wear is higher with methanol fuel operation and needs to be improved. On the other hand methanol fuel operation results in lower port deposits to gasoline fuel operation. The higher power drop in the case of methanol was attributed to a fault in the spark plug.

After changing the spark plug the full power was restored. The power developed by the engine when running on methanol fuel during the entire operation was satisfactory.

4.0 CONCLUSIONS:

4.1 Oil B resulted in ring sticking and therefore cannot be used for field applications.

4.2 Methanol fuel operation with oil C and Oil C + additive w showed no ring sticking. The top ring wear was almost double with methanol fuel as compared to gasoline fuel.

4.3 Methanol fuel operation reduced the exhaust port blocking, which may help in reducing the power loss of engine.

ES

TABLE(1)

Results of Wear And Deposit Test (22 hrs)

PARAMETER		GASOLINE + 3% OIL A	OIL B(castor)	90 M + 10G + 2% OIL C (59770)	OIL C + Additivew	Remarks	METHOD
Piston Skirt		8.11	7.45	6.12	5.73		IP 247/69
Piston under Skirt		9.75	8.72	6.0	7.75		"
Piston under Crown		3.33	0	0	0		"
Crown Cutting		10	10	10	10		"
Ring Sticking,	Ist	10	7	10	10		"
	2nd	10	9	10	10		
Ring Grove Deposits	Ist	0	0	0.69	0		"
	2nd	1.94	0	0	0		
Ring Grove Filling, %	Ist	-	18.0	10.45	13.35		
	2nd	-	2.3	4.0	5.2		
Ring Land(Lacquer)		2.91	0.325	0	0		"
Ring Wear, mg	Ist	7.6	8.9	14.7	13.3		Wt. Loss
	2nd	3.8	1.0	9.8	6.7		
Piston Sezure		10	9.92	10	10		
Ring Wear during running-In, mg	Ist	18.9	28.0	20.9	23.4		
	2nd	13.7	25.7	21.2	25.1		

TABLE 2

Results of Wear And Deposit Test(160 hrs)

PARAMETERS	GASOLINE + 3 % OIL A	(90 M + 10G) METHANOL FUEL + 1.5 % OIL C Additive W
Piston Skirt	6.48	5.74
Piston under skirt	8.76	3.15
Piston under Crown	0.73	4.63
Crown Cutting	10	10
Ring Sticking		
Ist	9.5	10
IInd	10	10
Ring Grove Deposits		
Ist	0	3.2
IInd	0	0
Ring Grove Filling %		
Ist	-	-
IInd	-	11
Ring Land(Lacquer)	0	0.59
Exhaust Part Blocking, % area.	31.78	Nil
Maximum Power Drop %	6.10	13.66*
No.of Spark plug fouled.	2	Nil
Ring Wear, mg		
Ist	12.64	36.9
IInd	25.2	23.2
Avg. Cylinder Wear,mm,	0.008	0.014
Wear during running In mg		
Ist	20.6	43.9
IInd	21.2	26.4

* This Power drop is caused due to spark plug problem.

APPENDIX I

a) **Running -In Schedule:**

DURATION - 8 Hours.

SPEED, ENGINE	R.P.M BRAKE	POWER H.P.	K.W.	DURATION MINUTES	TRANSMISSION
Idling (1000)	-	-	-	30	Neutral
2000	-	-	-	30	"
3000	635	0.35	0.26	60	Top Gear
3500	740	1.25	0.92	60	"
4000	845	2.4	1.77	60	"
4000	845	2.8	2.06	60	"
4500	950	3.5	2.58	60	"
4500	950	4.0	2.94	60	"
4500	950	FULL	THROTTLE	60	"

b) **Wear And Deposit Test:**

Duration - 22 Hours.

Stabilization Period

3500	740	2.3	1.65	60	Top

Test Cycle:

3500	740	2.3	1.65	60	Top
4000	845	3.4	2.54	90	"
2000 (Idling)	-	-	-	30	Neutral

Repeat 7 test Cycle in order to complete 22 hrs. of Engine operation.

c) **Wear And Deposit Test:** DURATION 160 hrs.

SPEED , ENGINE	R.P.M. BRAKE	POWER H.P	K W.	DURATION MINUTES	TRANSMISSION
Idling	-	-		2	Neutral
1500	125	No Load		2	Ist
2500	335	"		3	2nd
4000	845	"		3	Top
4500	950	NOTE POWER AT W..O.T		180	Top
3500	740	2.3	1.65	120	"
3000	635	No	Load	110	"
1000 (Idling)	-	-	-	30	Neutral
Shut Down	-	-	-	30	-

Repeat 20 Cycles in order to complete 1600hours of Engine operation.

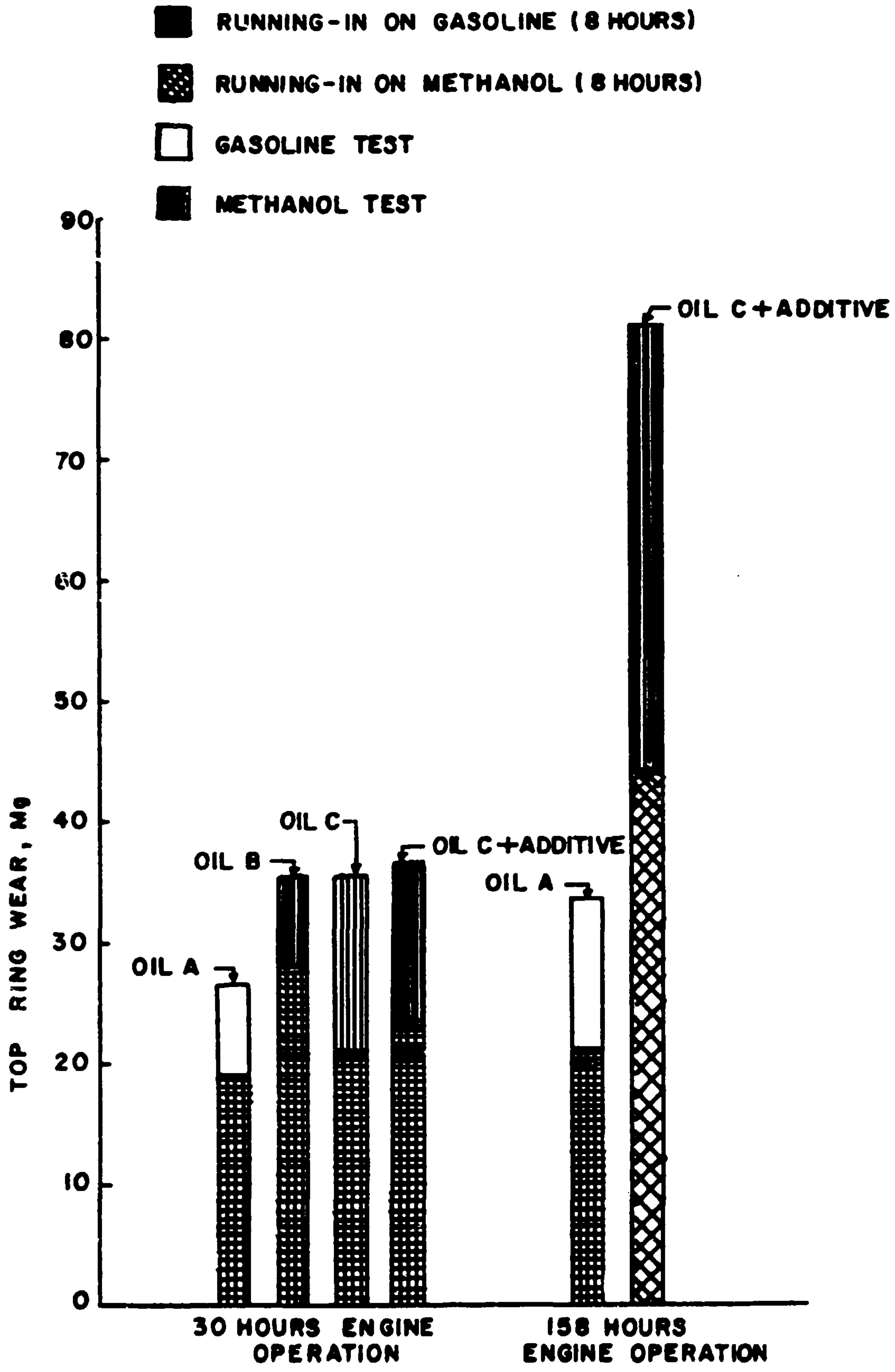


FIG. 1-EFFECT OF ENGINE OPERATION ON TOP RING WEAR.

APPENDIX 9

Re: Methanol Engine Oils from LUBRIZOL

1. 4-Stroke Engine Oils.

1.1 The additive package used is OS 66 839.

Typical analytical data are

Sulfated Ash	% wt.	6.71
Zinc	% wt.	0.71
Phosphorus	% wt.	0.64
Calcium	% wt.	1.71
TBN		45.0
Specific Gravity		0.96
Visc at 100°C, cSt		210

1.2 The additive package OS 66 839 A is giving the same analytical data. It is composed of components, which could be produced later at LIL-Bombay, if sales volume justifies the action.

1.3 Typical SAE 10W/30 engine oils successfully tested in the modified methanol Ford VD-Test (2.3 engine) are composed of

21.0 % wt. OS 66 839
\+ 2.5 % wt. LZ 73 22
\+ 0.3 % wt. LZ 66 62
in base stock 130 Neutral
= OS 59 567

1.4 The analytical data of OS 59 567 are

Sulfated Ash	% wt.	1.41
Zinc	% wt.	0.15
Phosphorus	% wt.	0.13
Calcium	% wt.	0.36

TBN	9.3
Specific Gravity	0.89
Visc at 100°C cSt	11.2
CCS at -20°C cP	33.0

1.5 A typical SAE 20W/40 methanol engine oil based on the additive package OS 66 839 would contain:

$$\left.\begin{array}{l}\text{21 \% wt. OS 66 839}\\ \text{in base stock from Indian Oil Co.}\\ \text{60 \% vol 150 Neutral}\\ \text{40 \% vol 600 Neutral}\end{array}\right\} = \text{OS 70336}$$

1.6 The analytical data of OS 70 336 are

Sulfated Ash	% wt.	1.4
Zinc	% wt.	0.15
Phosphorus	% wt.	0.13
Calcium	% wt.	0.36
TBN		8.5
Visc at 100°C cSt		15.6
CCS at -10°C cP		3150

2. Two-stroke Engine Oil

2.1 The ashless two-stroke Engine Oil OS 59 770 is fully mixable with neat methanol.

2.2 The base stock of OS 59 770 is a synthetic material (Polyglycol). This oil should be used at

50 : 1

in neat methanol fuel.

The typical viscosity data are

Visc at 100°C	22.07 cSt.
Visc at 40°C	139.9 cSt.

APPENDIX 10

Indian Institute of Petroleum
(Engines Laboratory)

Brief report on Lubrication and Wear Studies on a glow plug assisted pure methanol fuelled Kirloskar-AV1 Engine

Report No. EL0685 May 1985

Report by

A.K. Gondal
P.C. Nautiyal
H.C. Wolff

Approved by

S. Singhal

1.0 INTRODUCTION

This work was carried out on a Kirloskar AV1 engine to study the lubrication requirements of a methanol engine. The cylinder head of the engine was modified and optimised as described elsewhere* so as to fit a glow plug for methanol combustion. A number of studies have suggested that the current tests used to define lubricant quality need modifications to adequately define lubricant needs when methanol is used as primary fuel. The major deficiency of existing lubricants is reported as the control of cylinder bore and piston ring wear. Particularly, the low temperature conditions have been found to aggrevate this problem. In order to study the lubrication and wear phenomenon in methanol engine, the work was planned in two phases. The first phase comprised of long duration tests to study lubricant degradation, deposit formation and engine component wear. The second phase of work consisted of the top chrome plated ring wear study using Radiotracer technique.

2.0 INSTALLATION OF TEST BENCH AND OPTIMISATION OF ENGINE

2.1 Installation of test bench

The test bench already installed was checked for long duration tests. The pyrometers and temperature indicators

---

* See appendix 6.

were calibrated upto their full range using millivolt feeder and subsequently checked by heating oil. The water brake dynamometer was also calibrated statically as per manufacture's procedure. The calibration was cross-checked by running engine as diesel under rated conditions. This engine test showed that the system was satisfactory for beginning the testing of lubricants. However, further improvements of the measuring equipment, particularly, the brake, are required to improve the test repeatability.

The existing tank of 20 litres capacity was found unsuitable taking into account the high volumetric consumption of methanol. A 40 litre capacity was installed taking also into account the long term tests. During trial runs on methanol, problems were faced due to formation of methanol vapours in the fuel system. This was attributed to heating of injection pump and fuel lines. The problem was, however, not faced during actual tests because the fuel supply point was raised 2 m above the engine test stand.

2.2 Selection of Operating Conditions

On the basis of available literature and experience of running similar tests, it was decided to run tests reflecting severe conditions so as to reduce the test duration as well as get discernible data from different tests. Problems were faced during initial runs on the modified cylinder head for methanol operation as follows:

1) For engine condition as planned for tests, the wattage requirement of glow plug was higher than its rated capacity resulting thereby in frequent failures.
2) The glow plug location was such that its seat and the injector hole in cylinder head were very close, which resulted in breakdown of the intermediate wall during operation.
3) The glow plug was not easily replaceable.

These problems were subsequently solved by incorporating suitable modifications and testing the engine under a set of operating conditions, optimising it based on combustion pressure time data and employing a specially designed glow plug with built in thermocouple. Keeping in view the above parameters, a 50 hour test was devised as described in Table 1.

3.0 FUEL & OIL ANALYSIS

The methanol samples taken from the barrel as well as the injection pump were analysed for presence of Al and Fe. This was intended to give indications as to the type of metal impurities resulting from corrosion which may be ingested by the engine and could be detrimental for the engine during the tests. The lubricating oil is planned to be analysed for physico chemical properties, wear metals and presence of functional groups as soon as the analytical facilities are working accordingly.

Oil samples in the 50 hours tests were drawn periodically at an interval of 10 hours and analysed for viscosity, wear metals and neutralisation value. The samples were taken by draining first 200 cc of oil from the crankcase, then collecting 100 cc sample from the engine; adding 100 cc fresh oil to the 200 cc drained oil and transfering it back to the engine. This sampling procedure was standardised for all the tests to have a uniform sampling procedure.

4.0 RING WEAR STUDIES ON METHANOL ENGINES USING RADIOTRACER TEST METHOD

The lubrication and wear studies carried out during phase I on methanol engine showed performance of various lubricants with diesel and methanol engines in respect of deposits, wear of components and lubricant degradation. The radiotracer wear tests were planned to study closely the top piston ring wear of direct, bifuel and methanol engines using different lubricating oils. This was done as the top piston ring wear reflects interaction between engine fuel quality and lubricant performance. Further these tests have a more reliable assessment of variables as the tests can be done on the same assembly without involving dissassembly and rebuilding thereby resulting in accurate wear determination. A pressure pick up will be installed in the cylinder head as a means to control the engine combustion closely. The details of the tests planned are given in TableIII.It is hoped that the analysis of long duration test results and the radiotracer wear tests will enable to qualify a lubricant formulation compatible for methanol engines.

4.1 Test Schedule

a) Running in: The running-in of the ring/liner will be done for a duration of 10 hours as per following schedule:

i) Idling - one hour
ii) Part Load - four hours
iii) Full load - five hours

b) Tests : Tests will be carried out as given in Table II. The engine conditions that will be maintained during the tests are :

Speed - 1600 rpm
Load - 6.6 bhp
W.J.Temperature - 40°C
Oil temperature ~ 70°C, as observed.

In addition, a reference test of 8 hours duration on diesel fuel and Type III Lubricant will be carried out at the beginning and end of the experiments for a comparative analysis.

5.0 RESULTS & DISCUSSIONS

The results of ring wear after the 50 hr test are presented in Table V & Figure 1. From the Figure, it can be seen that with running time, the total wear of the rings increases for each assembly, whereas the top ring wear shows a different trend. The top ring wear seems to be more a function of fuel and lubricant combination for a given test. The increase in wear of piston rings with subsequent tests on an assembly is attributed to the fact that after each test, the engine is reassembled, thereby disturbing the conformability of rubbing surfaces which results in higher initial wear for each test. This can also be confirmed from results of the wear metal analysis.

This would need a correction factor to be applied to the wear results of subsequent tests before drawing any inferences.

As such, it can be seen from the top ring wear data that lubricants compatible with methanol do not necessarily perform well with diesel and vica versa. However, the compatible lubricant fuel combinations give comparative wear performance. This shows that the lubricants tested on a methanol engine under the severe running schedule(low water jacket temperatures, high loads) will perform equally well when compared with their diesel counterpart. Further, it can be seen that the two methanol compatible lubricants '222A' and 'LZ' give comparable results.

TABLE I

TEST CONDITIONS

DURATION	50 HOURS
SPEED	1600 rpm
LOAD	6.6 B.H.P.
W.J. TEMPERATURE	40°C ± 2°C
B.S.E.C. (METHANOL)	11.6 MJ/KW-hr
B.S.E.C. (DIESEL)	11.6 MJ/KW-hr
GLOW PLUG TEMPERATURE	1010°C ± 3

TABLE II

TEST SCHEDULE

SN	Assembly	Test No.	Fuel	Lubricant
1	D1	1st	Diesel	Type II
2	D2	1st	Diesel	Type II
3	D3	1st	Diesel	Type III
4	D4	1st	Methanol	Type III
5	D3	2nd	Methanol	222A
6	D2	2nd	Methanol	LZ
7	D3	3rd	Diesel	222A
8	D4	2nd	Methanol	LZ
9	D3	4th	Diesel	LZ
10	D4	3rd	Methanol	222A
11	D5	1st	Methanol	LZ
12	D5	2nd	Methanol	Type III
13	D5	3rd	Diesel	LZ

TABLE III: EXPERIMENTS WITH IRRADIATED PISTON RING: NOTATIONS

L1 - Type III LUBRICANT
L2 - 222A
L3 - LUBRIZOL
F1 - DIESEL
F2 - BIFUEL
F3 - METHANOL
C - CALIBRATION RUN (TWO HOURS)

TOTAL CYCLE - 24 hrs. with 6 hr. of test run each.

Cycle 1 LUBRICANT-L1	C F1 C F2 C F3	Cycle 2 LUBRICANT-L2	C F3 C F2 C F1	Cycle 3 LUBRICANT-L3	C F3 C F1 C F2
Cycle 4 LUBRICANT-L2	C F2 C F3 C F1	Cycle 5 LUBRICANT-L1	C F3 C F1 C F2	Cycle 6 LUBRICANT-L3	C F1 C F3 C F2
Cycle 7 LUBRICANT-L2	C F1 C F2 C F3	Cycle 8 LUBRICANT-L3	C F1 C F3 C F2	Cycle 9 LUBRICANT-L1	C F3 C F1 C F2

TABLE IV

Ring Wear During running in

S.No.	Assembly	Ring wt. Loss(mg.) Ist	IInd	IIIrd	IVth
1.	D1/	92.0	72.6	47.7	20.1
2.	D2	10.8	19.6	16.2	17.7
3.	D3	8.2	9.7	10.9	10.3
4.	D4	26.2	28.4	26.0	25.5
5.	D5	26.0	34.8	27.8	18.4

TABLE V

Piston Ring Wear Data

S.No.	Assembly/Test	Piston Ring Wear (mg) I	II	III	IV
1.	D1/1	186.9	55.5	21.4	32.9
2.	D2/1	42.0	29.3	22.3	25.6
3.	D2/2	113.0	41.7	27.6	31.4
4.	D3/1	25.4	19.1	16.9	12.8
5.	D3/2	27.1	44.8	30.0	33.2
6.	D3/3	54.1	45.1	29.1	32.0
7.	D3/4	62.0	81.5	47.8	47.4
8.	D4/1	47.5	19.9	11.2	14.7
9.	D4/2	35.0	29.6	17.1	27.2
10.	D4/3	43.1	41.3	22.8	32.0
11.	D5/1	29.9	49.3	22.7	48,7
12.	D5/2	60.2	52.6	34.6	53.1
13.	D5/3	121.1	41.9	25.3	37.1

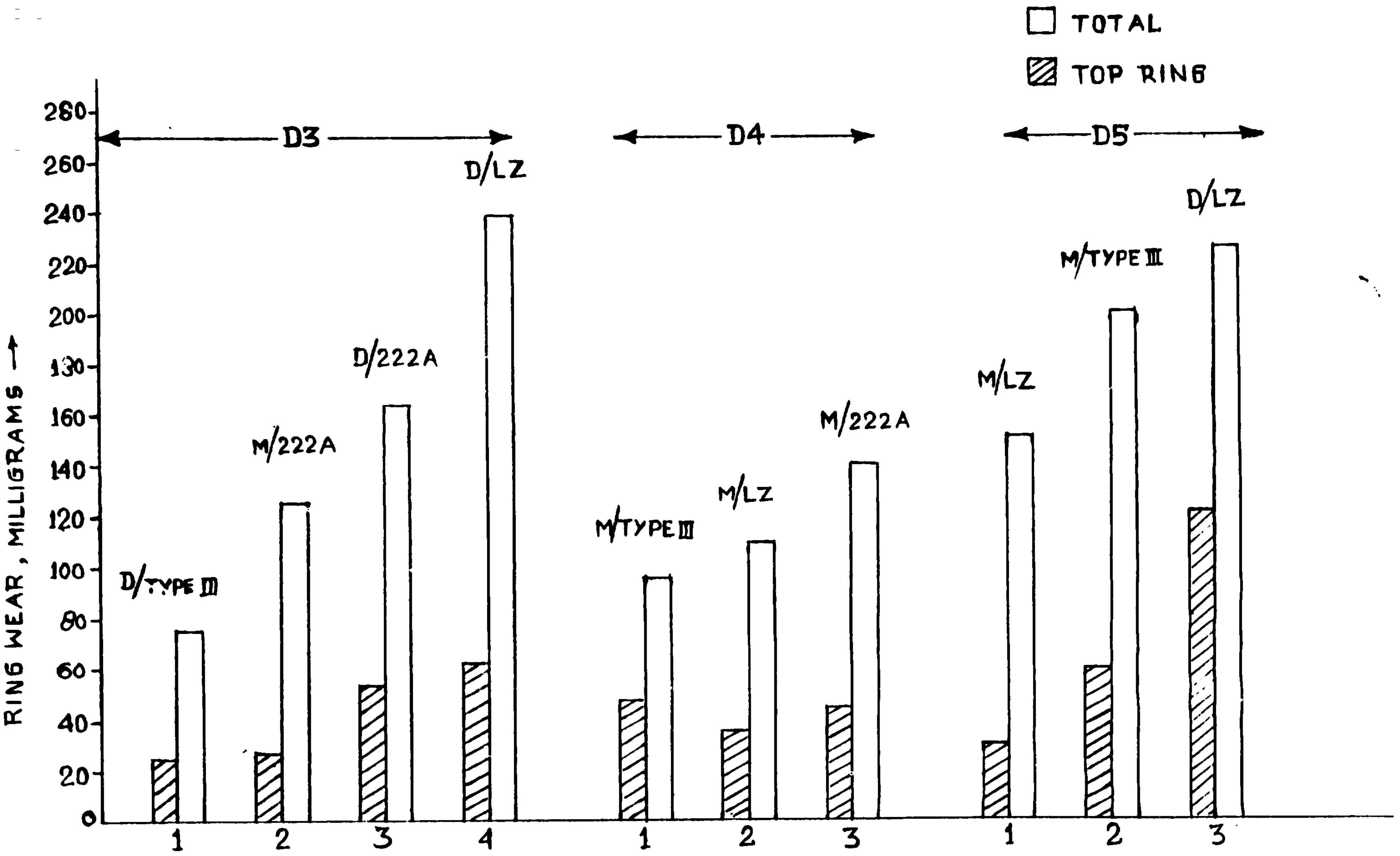


FIG. 1 RING WEAR DATA

TABLE VI

Piston Ring Clearances

S.No.	Assemble/ Test	Ring Gap (mm)								Side Clearance (mm)							
		Before Test				After Test				Before Test				After Test			
		I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
1.	D1/1	0.35	0.50	0.45	0.50					0.07	0.04	0.06	0.05				
2.	D2/1	0.38	0.38	0.40	0.40	0.40	0.45	0.45	0.50	0.04	0.04	0.05	0.05	0.05	0.04	0.05	0.04
3.	D2/2					0.40	0.50	0.50	0.50					0.08	0.05	0.05	0.05
4.	D3/1	0.35	0.35	0.35	0.35	0.38	0.40	0.40	0.40	0.04	0.03	0.05	0.04	0.05	0.04	0.05	0.04
5.	D3/2					0.40	0.42	0.44	0.45								
6.	D3/3																
7.	D3/4																
8.	D4/1	0.38	0.45	0.40	0.50	0.40	0.45	0.40	0.50	0.05	0.04	0.05	0.04	0.05	0.04	0.05	0.05
9.	D4/2																
10.	D4/3	0.42	0.47	0.40	0.60	0.42	0.50	0.45	0.65					0.06	0.05	0.05	0.05
11.	D5/1	0.35	0.35	0.35	0.35	0.40	0.45	0.45	0.50	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04
12.	D5/2																
13.	D5/3																

TABLE VII

Neutralisation Valve of Oil
Drained At Ten Hour Intervals

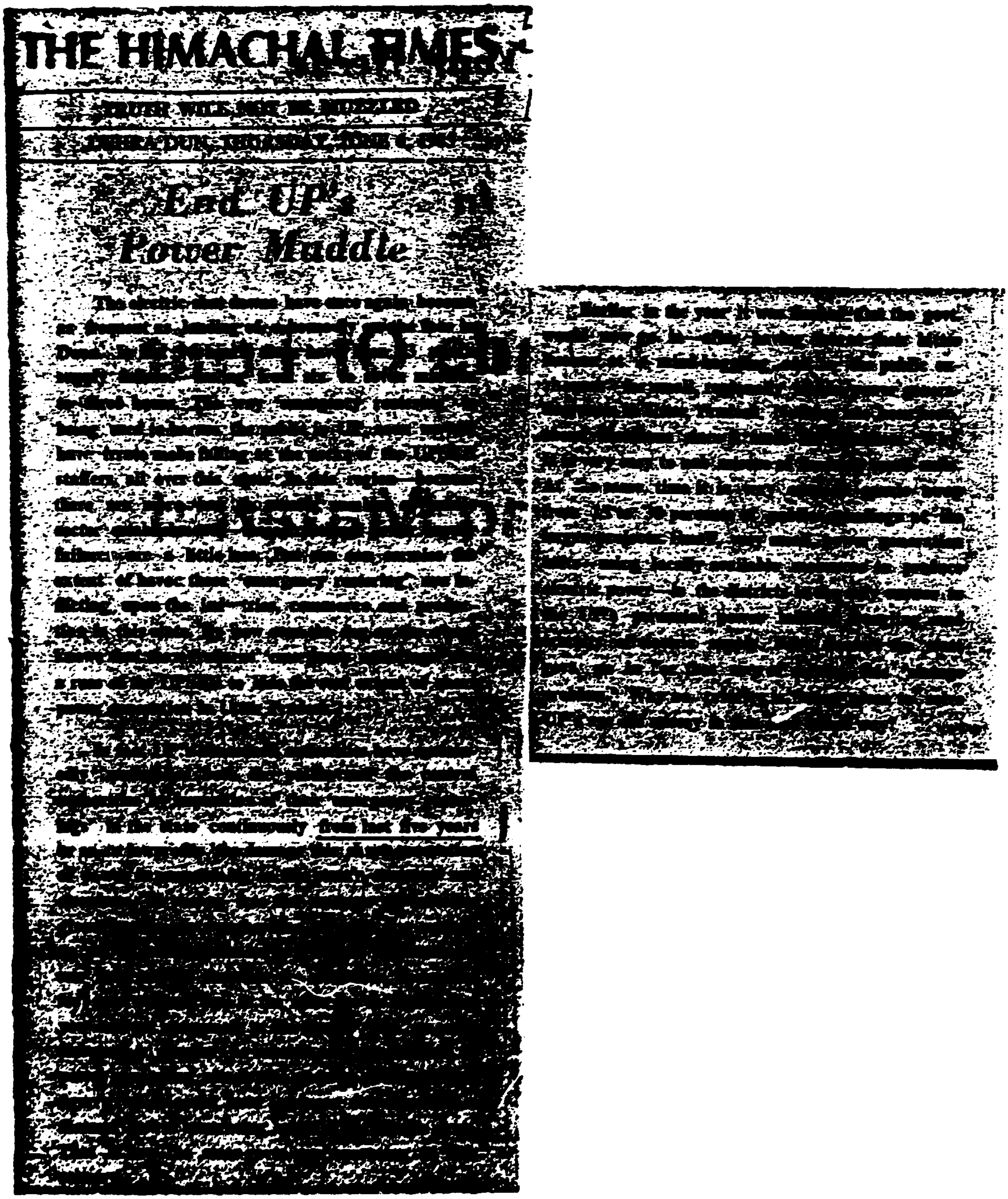
S. No.	Assembly/ Test	T. B. N.						T. A. N.					
		0	10	20	30	40	50	0	10	20	30	40	50
1.	D1/1	4.25	1.80	1.50	1.45	1.02	0.80	1.08	0.99	1.10	1.12	1.19	1.39
2.	D2/1	4.25	1.82	1.34	1.30	1.24	1.02	1.08	1.16	1.29	1.44	1.45	1.43
3.	D2/2	6.21	2.96	2.86	2.43	2.45	2.77	2.49		2.24	1.96	2.07	2.08
4.	D3/1	5.40	3.62	2.47	2.19	1.99	1.80	1.31	1.49	1.25	1.31	1.31	1.43
5.	D3/2	8.20	8.07	7.60	6.62	6.37	6.12		2.59	2.76	2.81	2.78	3.18
6.	D3/3	8.20	6.23	2.73	2.53	2.01	2.01		2.59	2.69	2.69	3.20	2.90
7.	D3/4	6.21					1.81	2.49					2.88
8.	D4/1	5.40	5.62	4.99	4.75	4.37	4.24	1.31	1.47	1.41	1.43	1.48	1.52
9.	D4/2	6.21					3.42	2.49					2.50
10.	D4/3	8.2					3.51	2.49					3.42
11.	D5/1	6.21											
12.	D5/2												
13.	D5/3												

TABLE VIII

Wear Metal Analysis of Oil Drained at 10 Hours Intervals

S.No.	Assembly/ Test	Fe (PPM)						Al (PPM)						Cr (PPM)					
		0	10	20	30	40	50	0	10	20	30	40	50	0	10	20	30	40	50
1.	D1/1																		
2.	D2/1		23	50	64	71	72												
3.	D2/2		40	40	45	55	180						25						
4.	D3/1																		
5.	D3/2		30	40	40	50	50	50	50	50	50	50	50						
6.	D3/3																		
7.	D3/4																		
8.	D4/1																		
9.	D4/2																		
10.	D4/3																		
11.	D5/1																		
12.	D5/2																		
13.	D5/3																		

The missing analytical data indicate the inability of the analytical group to support the project due to frequent power cuts.



THE HIMACHAL TIMES
TRUTH WILL NOT BE MUZZLED
DEHRA DUN, THURSDAY, JUNE [illegible]

End UP's Power Muddle

[illegible]

Engine Details

1.	No. of Cylinder	One
2.	Rated Power	5 bhp
3.	Rated Speed	1500 rpm
4.	Bore	80 mm
5,	Stroke	110 mm
6.	Swept Volume	553 cc.
7.	Compression ratio	16.5
8.	Injection release pressure (diesel)	2800 psi
9.	Injection release pressure (methanol)	
10.	Pump plunger dia (diesel)	7 mm
11.	Pump plunger dia(meth.)	8 mm

Indian Institute of Petroleum

Tests on Kirloskar AV1 Engine to Evaluate Performance of Lubricants with Methanol.

Report No. EL1185 May, 1985

Reported by

A.K. Gondal

Approved by:

S. Singhal

TESTS ON KIRLOSKAR AV1 ENGINE TO EVALUATE PERFORMANCE OF LUBRICANTS WITH METHANOL

Reported by A.K. Gondal

1. PREPARATION OF ENGINE:

The following measurements and testings were done before starting test on a new piston ring liner assembly:

a) Injector Opening Pressure.

b) Cylinder liner measurements.

i) Surface roughness: The cylinder liner roughness was between 50 and 100 micron as checked on thrust and anti-thrust sides at distances of 15 mm and 45 mm from top.

ii) Measurements: The diametric measurements were taken on thrust/antithrust side and at right angles to it at the distances of 15 mm, 45 mm, 90mm, 110 mm and 170 mm from top. These distances represent different locations of ring travel.

c) Piston Rings: They were checked for side clearance when fitted in the piston and gap when fitted in standard liner (Appendix). The rings were weighed.

d) Crank shaft big end and small end were checked for clearances (Appendix). Similarly inlet valve exhaust valve, guides and seat in cylinder head were also checked.

e) Before assembly, all the parts were cleaned and the rubbing surface coated with lubricating oil. The injection advance was set carefully to 27° before TDC Tappet clearances were carefully set (Appendix). All nuts tightened to proper torque while assembling.

f) 3.4 kgm of lubricating oil was put in the crank case.

g) Bumping clearance was carefully measured (Appendix).

2. Starting the engine:

The fuel level and pyrometers were checked. Any air in the injection pump was removed through the vent screw. Load on the dynamometer was kept to minimum. The rack was brought to minimum position. The glowplug was heated for 60 sec, when methanol is used as the fuel till the glowplug had attained a temperature of 1000°C. The engine was cranked to around 200 revolutions per minute and then decompression and rack opening is done simulta-neously.

3. Running-in Schedule

Duration hrs.	Speed r.p.m.	Load b.h.p.	W.J. Temp. °C
1/2	1100	No load	Record
1	1300	1.185	70°C
1	1300	2.37	"
1	1500	2.74	"
1	1500	4.1	"
1	1700	4.65	"
1	1700	6.2	"
1/2	1700	No load	"

After running-in the oil was drained and the measurements taken as done earlier. Before reassembly, the piston ring wear and test parts were carefully observed for any abnormal deposits & wear. The engine was flushed before reassembly with the test lubricant.

The engine is absolutely dried from outside and checked for any oil leakage.

4. TEST

After running-in if the test was to be run of diesel fuel, the engine was assembled as such. In case the test was on neat methanol then following points were checked.

i) The cylinder head with glow plug fitted in it was carefully checked for all clearances and then assembled.

ii) Injection timing was set carefully to 30° b.t.d.c.

iii) All electrical connections through rectifier were checked.

Engine Conditions

Duration	50 hrs
Speed	1600 rpm
Load	5.6 bhp
W.J. Temp	40°C

The water jacket temp. was set before starting the engine as above.

After starting the engine and achieving the conditions, proper record was made on an hourly basis of the engine conditions including oil and exhaust temp. Any stoppages, abnormalities were to be carefully recorded.

5) FUEL ANALYSIS

a) Diesel Fuel: Complete physico-chemical analysis cf fuel is done and the same diesel fuel is used for all the tests.

b) Methanol Fuel: The methanol fuel is analysed specially for impurities e.g. Al. metal. Methanol sample is drawn from the injector pump and analysed for presence of rust (Fe, Cu, Al, Cl). It should be carefully noted that the Al. should be less than 5 ppm and Cl. less than 1 ppm.

APPENDIX

1) Ring gap

0.35 to 0.4 mm.

2) Ring side cl.

0.04 to 0.05 mm - Comp ring

0.04 to 0.07 mm - Oil ring

3)	Pist on to liner cl.	0.09 mm
4)	Small end bearing cl.	0.023 to 0.069 mm
5)	Main bearing cl.	0.076 to 0.114 mm
6)	Valve inlet	0.1 mm
	exhaust	0.1 mm
7)	Liner ovality	.038 mm
8)	Crank shaft ovality	.075 mm
9)	Tappet cl.	INLET 0.25 mm
		EXHAUST 0.30 mm
10)	Bumping cl.	0.914 mm to 1.105 mm

(on valve depression 3.81 mm to 0.000 mm respectively)

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NOVEMBER 1985

APPLICATION OF ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES
IIP, DEHRA DUN, INDIA

DP/IND/82/001

APPENDIX TO THE FINAL REPORT DATED JUNE 1985 *

Prepared for the Government of India by the
United Nations Industrial Development Organization
Acting as Executive Agency for the United Nations Development Programme

Based on the work of Mr. Hans C. Wolff
Expert on Lubrication and Wear
Characteristics of I.C. Engines
Under the post: 11-05

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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Contents

1. Introduction

The Indian Institute of Petroleum, Dehra Dun, has organized from 18. Nov. to 22. Nov. 1985 "The IX National Conference on I.C. Engines and Combustion" (Organizer Mr. Sudhir Singhal).

During this conference more than 200 leading scientists and engineers from universities and engine manufacturers all over India and some guests from abroad have discussed all aspects of

- Application of Alcohols and other Alternative Fuels
- Engine/Vehicle Emissions and Air Pollution
- Engine Combustion and Mathematical Simulation of Processes
- Engine Design and Development
- Engine Lubrication and Tribology
- Fuel Quality, Economy, Engine Performance, Experimental Techniques and Instrumentation.

On request of the organizer the writer of this report has prepared a paper "Lubrication of Methanol Engines" (see Appendix). The purpose of this paper was to summarize the latest results from the international literature and from the development of the engine laboratory of IIP in order to convince the Indian engine manufacturer that suitable engine oils for methanol engine development can be made available from IIP. - The writer was invited by IIP and UNIDO to present his paper personaly and to use the unique possibility to discuss detailed questions with the participants of the conference.

2. Achievements

2.1. The whole conference was a great success for the IIP. The organisation worked well. The timing was kept and the spirit of work was high. - All delegates obtained on arrivel already all papers in printing. This was a great help for fruitfull discussions.

The organisers must be congradulated to this successful conference.

2.2. The paper "Lubrication of Methanol Engines" was recieved with interest. Many personal discussions during the days of the conference took place at lunch and tea breaks. The information, that IIP has successfuly engine tested such an oil, was accepted.

2.3. It is now agreed between the interested parties (engine manufacturers, fleet operators, oil supplier-LUBRIZOL INDIA Ltd (LIL) and the IIP-engine laboratory) that the Indian Methanol Engine Oil "OS 70336" should be ordered through the IIP-engine laboratory. This measure will enable IIP to organize the production and quality control of this oil in co-operation with LIL. Since this oil is not yet a comercial quality the supply has to be organized this way.

2.4. The writer has realized with great pleasure that some of the recommendations (see final report dated 14 June 1985) have already been taken up. The first engine tests with radio activated piston rings showed the testoils in the same order as before. This is indicating that the test as such is useful. Further tests are planed.

3. Recommendations

3.1. The keyposition of a continous power supply has now been realizied by the management of IIP. A large generator set has been ordered. However, the writer is not convinced that this measure will solve the problem. It is improtant to realize that the quality of the power supply (no fluctuation of frequency and voltage even if large units are switched on) is the decisive question! In order to achieve this large changes in the power supply network within the IIP will be necessary and the new generator will have to run continously for certain applications like analytical equipment. The overhaul of the network and other measures like automatic power quality control will be rather costly. To avoid misinvestment it is recommended to organize a competent study by an expert team before the final investment takes place. Since several highly sophisticated analytical units, which were imported, are involved, it is recommended to use the assistance of experienced international experts. (e.g. Prof. Dr. Ing. H. Schaefer, Forschungsstelle für praktische Energiewirtschaft, D 8000 München 50, Am Blütenanger 71 - FRG).

3.2. The use of radio activated piston rings for the further development work in the Kirloskar AV 1 should be continued. (see recommendation 3.4., 3.5., 3.6. page 12 of the final report 14/06/85).

3.3. Since the supply of the methanol engine oil OS 70336 will be organized by the IIP-engine Laboratory this should be used to obtain a complete set of results on the methanol engine tests running in India. With this background information a very effective advise to the engine manufacturer and user will be possible.

3.4. Since the first real fleet trials with methanol buses in India are now in preparation it seems to be important, that the support by international UNIDO Experts to these tests is contiuned. These tests will have to run at least for 3 years.

4. Acknoledgement

4.1. The writer would like to thank Dr. Hans H. Seidel, UNIDO Vienna and Dr. M. Kamal Hussein UNDP New Delhi for their support by arranging the participation to the IX National Conference on I.C. Engines and Combustion.

This second contact to the colleagues at the IIP in Dehra Dun and the discussions with Indian engine builders were most fruitful.

4.2. Many thanks to the management of the IIP and in particular to Mr. Sudhir Singhal, who has taken the trouble beside is engagement as the conference organizer to arrange my stay and all the contacts so perfectly. It was a pleasure to see his successful team at work.

IX NATIONAL CONFERENCE
ON
I.C. ENGINES AND COMBUSTION

INDIAN INSTITUTE OF PETROLEUM
DEHRA DUN, INDIA
NOVEMBER 19-22, 1985

LUBRICATION OF METHANOL ENGINES

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Abstract

Research and development on methanol engines is going on in many parts of the world. Test fleets of buses and passenger cars are on the roads since several years. For diesel engine derived methanol engines the lubrication and wear problems seem to have been overcome.
For passenger car engines some problems under cold driving conditions are still recorded. For two-stroke engines very little results are known.

Results on engine tests and from fleet trials will be reported. Theories on the wear mechanism in methanol engines will be discussed. Some laboratory tests will be described.

Based on all these facts it will be tried to give to the engine construction industry some hints. how to prevent difficulties in methanol engines. The lube oil can help in certain cases but much more success can be achieved by obtaining complete combustion under all service conditions.

1. Introduction and Definition

Methanol will be the motorfuel of the longterm future because it can be produced from low grade coal economically. Its combustion characteristic is favourable to produce clean exhaust gases. High thermal efficiency has been achieved in methanol engines. To obtain a long engine life the lubrication is an important factor.

Research on the basic lubrication questions of methanol engines are going on in many parts of the world. The published results seem sometime controversial at the first sight. It is necessary to examine the results of practical field trials in detail to obtain a feeling for the significance of the results collected in laboratory tests. Only by putting together all these information in the form of a mosaic it will be possible to get a fully realistic picture. It will be tried to follow this line in order to show where we are and what area should be used for future development.

2. Fleet Test Results

2.1 Passenger cars

Large scale passenger car fleet trials are running in West Germany and USA since the end of the seventies. The methanol fuels used are M 15 (15 % methanol + 85 % gasoline containing 0,15 g Pb/l) or M 100 (85 to 93 % methanol + up to 15 % unleaded gasoline or light hydrocarbon components).

The M 15 test fleet in West Germany terminated its trial at the end of 1982. Out of the 892 cars, which did run since 1979 a total of 149 were monitored by used oil analysis [1]. In general these used oil analysis did not indicate a significant difference in engine wear comparing M 15 fuel and conventional gasoline. In few cases increased iron and copper content was observed in the M 15 fleet. This may be explained by more severe driving conditions and by lacking resistance of some particular engine parts towards methanol. - The rating of 40 M 15 engines, which were completely dismantled, resulted in good engine cleanliness and minimized wear. In agreement with the result of the used oil analysis the status of the M 15 engines was about comparable to engines fueled by conventional gasoline. Consequently it was stated that currently in West Germany available engine oils of the quality level API SF (SE)/CC fulfil the requirements of M 15 engines.

The M 100 passenger car test fleet (81 cars) in West Germany reported at the end of 1983 based on used oil monitoring of 54 cars the following results: [2]

a) Conventional high quality engine oils can raise trouble by building up of deposits in the intake system, where methanol droplets hit blow by gases. Experimental oils gave great improvements in this respect.

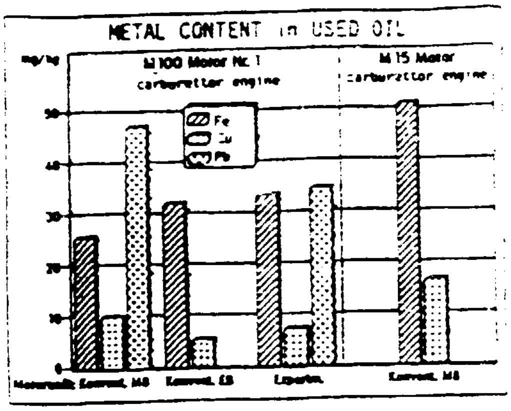


Fig. 1

b) Iron content in used oils were not higher on average in carburator engines except in those running under very low temperature conditions. - (Fig. 1)

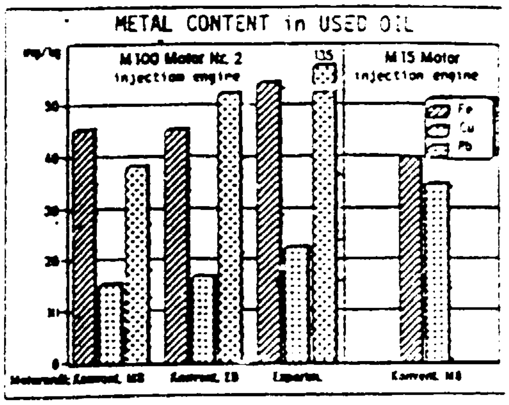


Fig. 2

Injection engines observed higher iron content. This might be due to the uncomplete evaporation of the M 100 before entering the combustion room. (Fig. 2)

In all types of engines the variation of the iron content was very high. This indicates that only under certain conditions higher wear occurs.

d) To control all conditions for passenger cars running on M 100 specialized engine oils have to be used and special engine design features have to be observed.

Volkswagen Research [3] is reporting based on a 74 car fleet, which was run by normal customers, after 3 years service high mileage (Fig. 3) without engine overhaul. Meanwhile 3 cars have reached more than 200.000 km. Deposits in the inlet system were overcome by introducing special M 100 engine oils. Special design features to increase the engine temperature quickly after start up and excellent fuel/air mixing also under cold start conditions helped to obtain these results. - In the injection engines the piston rings coated with molybdenum showed higher wear as usual. By changing to normal piston ring material the wear was reduced to normal. Most trouble during the field trials occured due to contamination of the fuel.

VW-TEST FLEET - Private Drivers

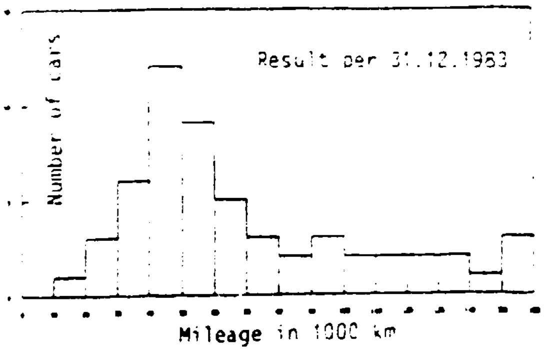
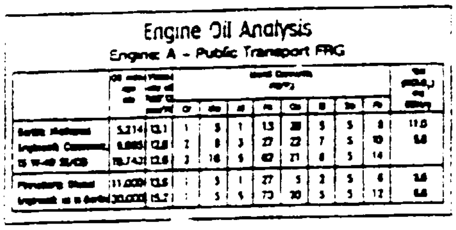


Fig. 3

Ford Motor Company [4] is reporting on its 40 car fleet (1981 Escorts) and the 582 production vehicles (1983 Escorts). Some of these cars have run over 200.000 km indicating that they had no lubrication problems. Ford in-house testing confirmed, however, as Volkswagen did, that chrome-coated piston rings are more durable than the molybdenum-faced rings. - Most problems during the field trials were concerned with cold start and cold drive-away. Methanol contamination of the luboil will occur during this type of operation. 45 % of the service claims were related to fuel contamination or misfueling.

R. Nichols, Ford, claims in June 1985 under "Future Directions" with regards to engine wear: "To date, the durability experience with methanol vehicles is considered to be satisfactory. Improved control of fuel quality is required in order to minimize the rate of fuel filter plugging, as well as reduce potential wear of parts. Improved oil formulations, especially for cold weather operation, should continue to receive a high priority."

2.2 Commercial Vehicles
The first Methanol-Buses from Daimler Benz and MAN in regular city service were run in Auckland (NZ) 1981 [5]. High wear was only observed at the beginning due to fuel contamination by Aluminium. If this Al enters the combustion room it burns to Aluminiumoxide, which is an abrasive. This type of wear is not a lubrication problem.- In Berlin (FRG) the same buses are running since 1982. This fleet contains since 1985 a total of 14 buses. The wear figures observed are as low as with comparable diesel buses. See Fig. 4 [6].



Engine Oil Analysis
Engine A - Public Transport FRG

Fig. 4

In Pretoria (S.A.) Methanol Buses are running since 1982 [7]. In San Francisco (USA) Methanol Buses have started regular service in 1984. There is the first two-cycle C.I. Methanol Engine, developed by General Motors, involved [8].
This world-wide set of citybus application of methanol engines derived from diesel engines in public service indicates that the lubrication and wear problems in these engines have been overcome. These engines are lubricated by commercial high quality diesel engine oils nominated by the engine manufacturers after long distance road trials. This type of oil was developed for long oil drain periods. It has initial TBN of 10 to 12. Oil change intervals for these methanol engines have now reached 20.000 km after controlling the buses in service by used oil analysis.

3. Laboratory Engine Tests

Standardized engine oil laboratory engine tests are normally run on very well defined test fuels in order to obtain reproducible wear results. To indicate to the contrary the influence of the fuel quality on wear the luboil was kept constant from M 0 over M 15 to M 100.

Results see Fig. 5 [9] and 6 [10]. The results may be summarized as follows:

- M 100 improves piston cleanliness and average varnish rating.
- Sludge formation with M 100 is higher under low temperature conditions compared to conventional fuel.
- M 100 fuel increases came and follower wear.
- Cylinder wear was found in some cases to be 10 times higher for M 100 compared with reference fuel.
- Inlet system deposits are a major problem with many M 100 engines.

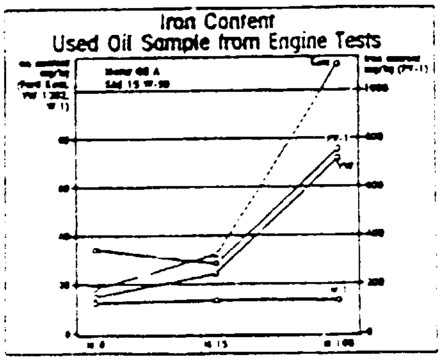


Fig. 5

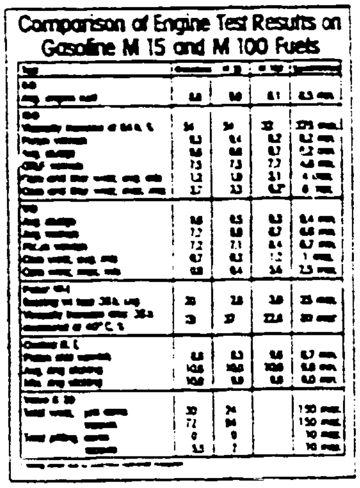

Comparison of Engine Test Results on Gasoline M 15 and M 100 Fuels

Fig. 6

To transform these results found in laboratory test engines into massproduction engines but still running under closely controlled conditions in the laboratory the cycling test conditions as defined for the modified ECE-15 emissions cycle (see Fig. 7) were used. The coolant temperature and the total running time turned out to be the most significant factors for engine wear (see Fig. 8).

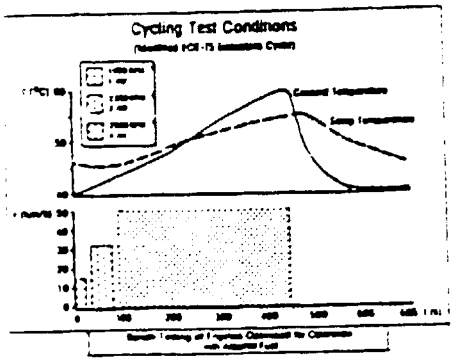


Fig. 7

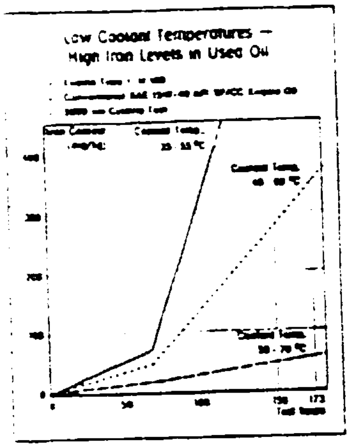


Fig. 8

Therefore the Indian Institute of Petroleum in its desire to develop an Indian test procedure for the evaluation of methanol engine oils has chosen 40° C as coolant temperature, high load and 50 hrs test duration in the Kirloskar AV 1 engine. - Since this test engine at the IIP Engine Laboratory can be used with radio activated piston rings more fundamental studies can be performed also.

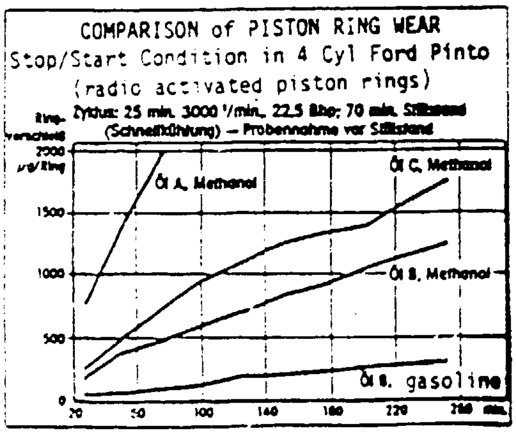


Fig. 9

K. M. Riches and C. Pinnington [2] have used a 4 Cyl Ford Pinto engine with radio activated piston rings to demonstrate the improvement obtained by using engine oil developed for methanol engines (Oil B, Fig. 9).

In USA a modified ASTM sequence V-D test procedure is used to evaluate engine oil quality in methanol fueled engines [11, 12].
Corrosive attack within the ring zone and formaldehyd as well as formic acid in the blow-by was found. Critical temperature for wear was realized when the oil temperature falls below 70° C. - The rusting phenomena depends also on the material and is therefore different from engine to engine.

There are several theories about the chemical mechanism leading to excessive wear [13]. All researchers agree on the formation of formaldenyde and formic acid. The attack by nitric acid was denied by SWRI [14] - Magnesium - based detergent additives were less effective in controlling methanol-related engine wear than was a calcium based additive. The chemistry of the ashless dispersant was also found to have an influence on the wear. Simply increasing the TBN of the oil was not effective. - An increase in valve train wear was observed with an aryl-zinc-type additive when compared to the alkyl-zinc-type additive [15].

It appears that fuel distribution (gasification, carburation or injection) contributes to the iron wear. Wetting of the cylinder liner by methanol leads to increased wear. - The initial drop size of the fuel plays a very important role in the start ability of the engine. For drop size of 100 microns, starting temperature must be above 55° C whereas reducing initial drop size to 10 microns allows starting temperature as low as -15° C. - The energy required to evaporate methanol is 5 times higher than that required for diesel fuel.

4. Laboratory Glas Wear Tests

To study corrosion problems, the influence of methanol mixing with the engine lubeoil and the metal wetting properties of lubeoil in the presence of methanol several glas wear tests have been suggested. S. E. Schwartz [16, 17] has developed these tests systematicly. By putting iron chips with water or methanol on an piece of a cylinder liner which was wetted with engine oil crevice corrosion was simulated (see Fig. 10).

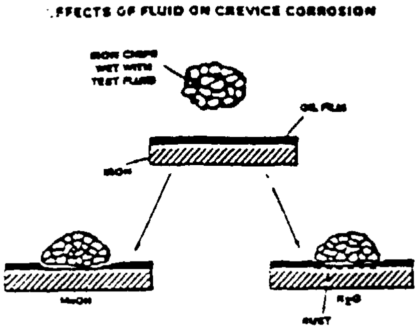


Fig. 10

Result: Methanol by itself, did not promote iron oxide formation. On the other hand, water, even through an oil film promoted iron oxide formation. -

To see the corrosive potential of the components of interest in blow-by gases (methanol, water, formic acid and water) a small drop of the test fluid (∼ 1,5 mm^3) was applied to a horizontal cast iron coupon (ATSM D 2570-73) wetted by oil (see Fig. 11).

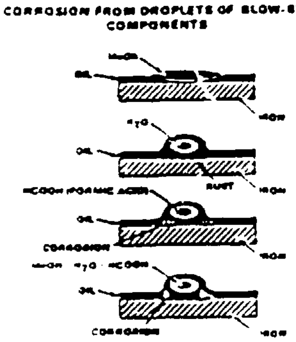


Fig. 11

Result: Methanol did not cause observable change in the surface of the iron whereas water showed rust. In all samples which contained formic acid, at concentration as low as 0.1 per cent, corrosion occured. A ridge formed at the edge of the test spot.

Oil and methanol mixtures showed the following phase composition. Mixing a base oil with methanol results in the two layers after a short period of standing. This indicates that base oils are not mixable with methanol. - Mixing a fully formulated oil with methanol results in three layers. The lower layer is predominantly oil containing a small amount of methanol. The second layer is viscous consisting of a yellowish white blend of oil and a high concentration of methanol. The third layer is predominantly methanol containing some oil additives. The cream layer can be completely eliminated by warming to boil off the methanol and stirring the mixture to redissolve the oil additives in the oil phases. -

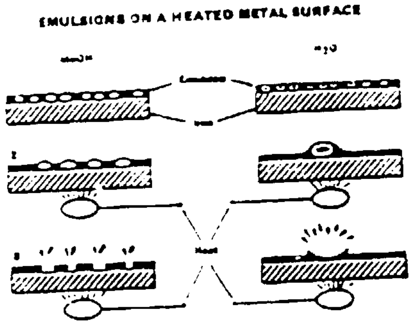


Fig. 12

Emulsion of methanol/oil or water/oil placed in a thin film on a hot iron surface showed different results (see Fig. 12). The water droplets coalsesced to form a large (several millimeters diameter) water drop and boiled of "explosively" (flash boiled). A slight depression which filled in immediately was seen in the oil film. -

The methanol/oil emulsion did behave differently. When spread in a very thin layer the methanol boiled out of the oil and a small hole was formed in the oil film. The hole was approximately one millimeter in diameter and remained visible for several seconds.

To study the metal wetting properties of lubeoil's in the presence of methanol a simple apperatus was used to determine the contact angle [2] see (Fig. 13).

If the contact angle is large, the oil tends to form a droplet. - This is indicating a rather poor wetting of the metal surface in the presence of methanol. If the contact angle is small the oil tends to form a film. - In order to change the "wetting power of the oil" some polar components can be mixed into the oil.

The addition of 0,3 % wt of phenole for example is reducing the contact angle by 50 %. The best result was obtained with a polar engine oil (see Fig. 14).

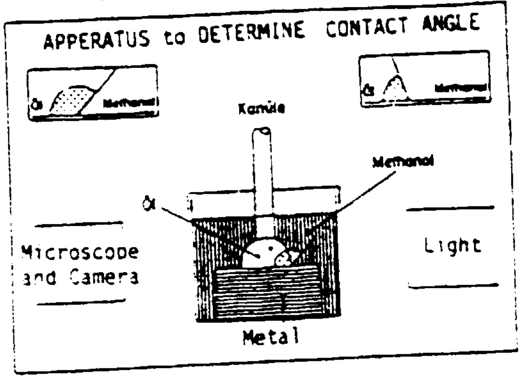


Fig. 13

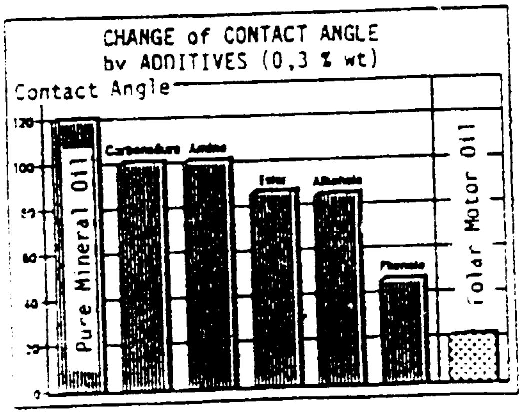


Fig. 14

Further observations in this test were: The change in contact angle also depended on the length of the hydrocarbon chain. If the chain had more than 12 C-atoms no change in contact angle did occur for a given "anchor group". No difference in contact angle was found using iron or chromium surfaces.

No difference in contact angle was found by changing the temperature between 25°C and 60°C.

On polished steel surface methanol always pushed away and displaced the oil film.

The "best high polar engine oil", however, was able to stay at the polished metal surface in the presence of methanol.

5. RESUME FOR THE ENGINE CONSTRUCTOR

Summarizing the experiences from the field trials and the result from laboratory engine and glasware tests it can be stated:

- Low methanol blends up to M 15 will show no significant increase in wear, if high quality engine oils API SF (SE) CC are used.
- M 100 for passenger car engines is requiring special oils mainly to prevent deposits in the intake system and wear in the upper cylinder part under cold driving conditions. The engine constructor can reduce these tendencies drastically by guiding the blow-by gases into the inlet system at a point where the methanol is already fully vaporized. The blow-by gases could be guided over a cool metal mesh system to condensate the oil mist and return this in liquid form direct into the crankcase.
- The constructor must prevent liquid droplets entering the combustion chamber in such a way that they might hit the cylinder wall. This is most difficult under start up and cold driving conditions.
- Complete combustion of the M 100 and fast warm up of the upper cylinder walls as well as coolant temperatures above 80°C are the "secrets" why city bus engines derived from diesel engines even running on M 100 show low wear figures with so-called "long distance high performance diesel oils".
- Extremely careful fuel filtration and suitable material in the fuel system to prevent impurities to enter combustion room are of great importance.

6. Future Outlook

Methanol production in India will be small for many years to come but the methanol price on the world market is low and will stay this way. Since India has to import large quantities of diesel fuel it could import instead methanol without changing its balance of payment. Using this methanol as fuel for city buses in congested cities would improve the air polution problems greatly. Therefore the first application of methanol in India should be in city buses. If the existing diesel engines are converted into "Methanol engines" by adding a fumigation system no lubrication problems should occur.

In the longer term India can produce methanol from natural gas, which is becoming available more and more. But this will also be an interim period only. In the real long term India will produce its methanol from low grade coal. This development will provide many jobs for the growing population and help to become independent from oil imports even in the long run. Since crude oil prices will increase after 1990, when world-wide the oil is becoming less, the methanol production from cheap coal will become economically.

Under these longer term aspects the development of real methanol engines should be started now. Again the field of buses and commercial transport should be the area to work in. This would minimize the fuel distribution cost for methanol. The fleet uses of methanol could dominate for a long time if this fuel is used for local transport in congested areas. - The lubrication of these engines will not be a barrier since the IIP has already available a suitable engine oil (OS 70336) which can be produced in India.

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