PROJECT

ESTEROL

BIO-ETHANOL / RME FUEL

CONTRACT N° XVII/4.1030/A/98-597

Final report

on

the project Development and testing of RME as ignition improver for neat bioethanol as diesel fuel - an extension of the so-called Esterol Project (contract No XVII/4.1030/Z/ 96-078).

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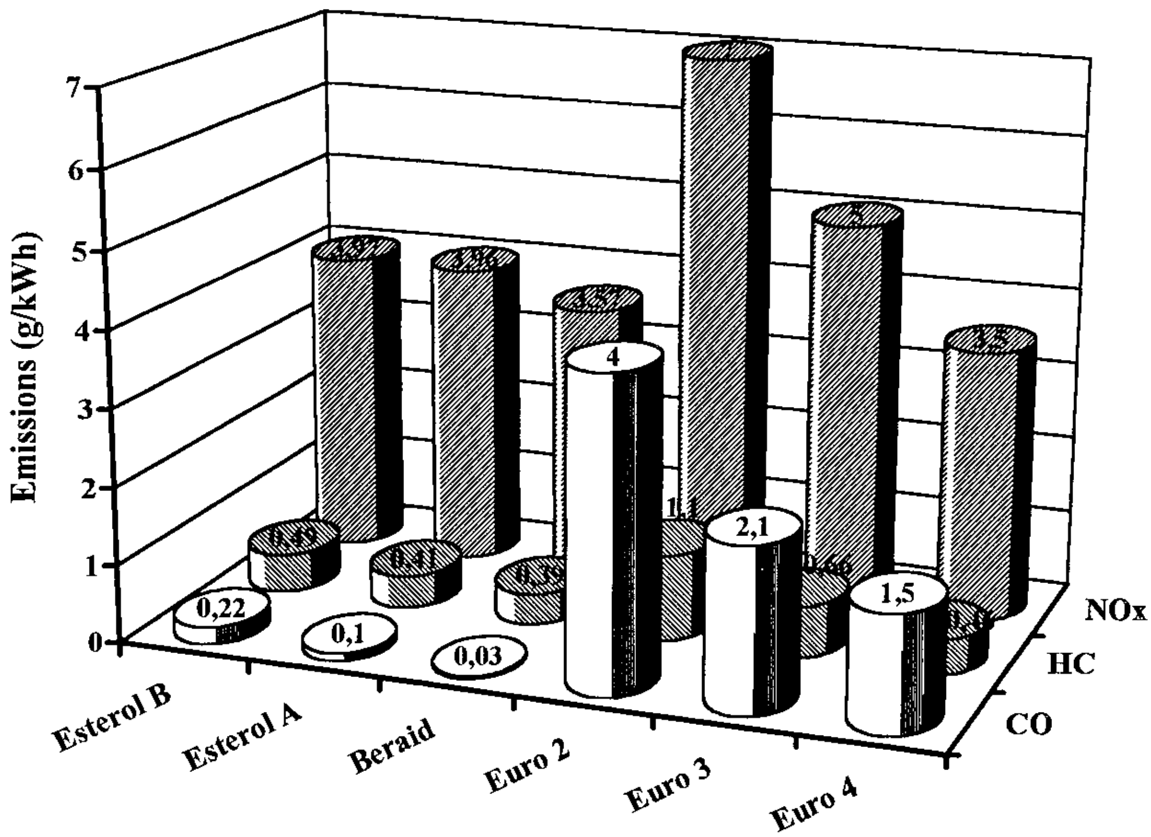

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Abstract

Neat alcohol fuels have been proposed and tried extensively since the days of the oil crises of the 1970ies, for use as motor fuel for diesel vehicles due to the possibility to produce alcohol from non-fossil, renewable raw materials, what would help the transport sector to increase its sustainability, and, also, to become environmentally more benign. Comprehensive field testing of bioalcohol has, accordingly, confirmed, that the alcohol engine technology is mature and, also, significantly more environmentally benign than conventional diesel fuel of fossil origin. The Swedish fleet testing of heavy duty vehicles on bioethanol fuels as carried through within the framework of a comprehensive State program for biofuels has added much to the knowledge and experience of the bioethanol option for more environmentally benign heavy duty transport.

There are several technical options for using neat ethanol as diesel fuels. The technique of preference has been to change the properties of the alcohol to acquire "diesel oil properties" in regard of the propensity of the liquid to ignite by compression in a diesel engine. Several chemical substances have been proposed and tried for the purpose. Organic nitric esters have proven to be the most effective ones. They suffer, however, of the problem of autocatalytic hydrolysis in the presence of water and are, therefore, unsuitable for use together with hydrous ethanol. Nitrogen-free substances like "Beraid" (which is a derivative of polyethyleneglycol) have then been tried with success in the Swedish vehicle field tests. However, some technical problems of technical, sustainability and of an economic nature remain to be abated and, possibly also to be removed.

The principal objective of the project have, accordingly, been to develop and to demonstrate the possibility to use RME as a low cost ignition enhancer in ethanol fuel for dedicated ethanol diesel engines. In case of success, technical problems, such as associated with too low lubricity of the neat alcohol fuel formulation, could be removed without loosing in regard of environmental benignity of the fuel. Further, the ethanol diesel fuel option would become more sustainable both in regard of technology and, also, regarding the renewable raw material base for the production of the fuel formulation. It also appears as if the new ethanol fuel formula containing RME as ignition enhancer could become significantly less expensive than the fuel formula presently in use (containing Beraid).

During the implementation of the project the objective to develop a new and efficient fuel formula for neat ethanol fuel, containing RME as ignition improver substance, has been successful. A number of suitable fuel formulas have been developed and characterized in regard of cold start properties, drivability etc. The optimum fuel composition was selected and applied in further field testing of a bus in regular city duty in the town of Örnsköldsvik. The exhaust gas emission characteristics have also been determined and found to emulate the properties of the fuel formula containing "Beraid" as ignition improver and which is presently used in all of the ethanol buses in Sweden (some 400). The field test of an ethanol city bus in the town of Örnsköldsvik has also confirmed that the new fuel formula, Esterol A, functions very well without any problems of cold start and drivability appearing. The fuel consumption seems to be somewhat lower than that of the reference fuel ("Beraid") by some 5% corresponding to the difference in combustion heat. Comparisons were enabled by the tests having been undertaken on the reference fuel composition during previous projects with the same test bus.

The project now proceeds during the present winter as the problem of the fuel's cold temperature properties has so far not been tested sufficiently extensively. Certain chemical agents, which will have to be added to the fuel in small amounts in order to avoid freezing out of certain of the RME components at cold temperatures, have been applied to the fuel formula, "Esterol A". In case of such "freeze-outs" during the present winter, other technical

fixes will also be tried as remedies. The goal is to extend the temperature range for Esterol A fuel to be liquid down to –25 °C.

Due to the good results so far obtained from the testing of the Esterol A fuel formula, the city bus traffic entrepreneurial company (Busslink AB) in Stockholm has demonstrated interest for the new fuel formula. In accordance with this, they are prepared to make 5 city buses available for a pilot bus trial in Stockholm during the present winter. The project is presently under formation and will be started within short.

The present report also includes an account of the work as carried through at VTT, Finland in 1999, in order to optimize the engine settings to enable the acquisition of optimum conditions (in terms of exhaust gas emission characteristics) for Esterol-20 fuel (20% ethanol in RME) use in ordinary, non-dedicated diesel engines. This work forms part of the present project. As the both parts of the Esterol projects I and II were partly overlapping, it was considered appropriate to report the results already in the final report for the Esterol I project (ref.1) together with the exhaust gas emission characterization work according to the ECE R49 test cycle. It was found that the exhaust gas characteristics for Esterol-20 fuel could be improved somewhat by advancing the fuel injection settings by 1,7 CA degrees relative to that of the best diesel oil quality (Environmental Class 1, EC1) fuel. Further optimisation should, however, be undertaken when considered appropriate.

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1. Introduction and prerequisites.

The use of neat alcohol as fuel for CI engines is not possible without adaptations being undertaken of the engine design and of the fuel to meet the requirements for compression ignition to occur in the engine. Several technical options for such adaptations exist and have also been developed and tried, especially after the two periods of oil supply crises facing the world during the 1970:ies. These possibilities have, in principle, been based on two alternative and different techniques, which can be characterised either as an engine modification method or as a fuel modification method. These two basically different methods have also been used in combination.

The method having been preferred by the engine manufacturers is featured by a combination of the two basic options as indicated. The main reason for this preference is that it minimises the problems of infrastructure when changing the fuel system. The basic features of the engine technology and of the fuel distribution system can be kept, what has guaranteed a rather rapid positive response from the crucial actors on the market, namely the engine and vehicle manufacturers.

The main problem for using neat alcohol as a diesel fuel consists in the low propensity for alcohol to ignite at the conditions achievable in ordinary, non-dedicated CHI engines. This problem can be solved in either one or in a combination of the two principal techniques indicated above. Accordingly, it is possible to increase the compression ratio of the engine, what increases the temperature of the compressed air in the combustion chamber. Secondly, there are chemicals, which can be included in the fuel formulation in order to increase the ignition propensity of the alcohol fuel. It is, however, not practical to increase the compression ratio so much as to cause ignition of the fuel alcohol being injected in the combustion chamber without also using the second technique, namely to increase the ignition propensity of the alcohol by the addition of a suitable chemical. It is, on the other hand, possible to use an efficient chemical ignition improver substance without increasing the compression ratio of the engine. This option requires, however, either that the alcohol is blended with the ignition improving substance to such a high percentage that would render the fuel prohibitively expensive as compared to the alternative method to use a combination of engine adaptation and fuel additivation, or, alternatively, that the ignition improving substance to be used would have to be so effective as to qualify as an explosive.

A number of different ignitions improving chemicals have been tried for the purpose as indicated. Most well known and used are chemicals belonging to the class of organic nitric esters (these are compounds between an organic alcohol and nitric acid). They are efficient and some of these compounds also qualify as explosives. They are, therefore, not to be used extensively due to safety concerns. Another reason not to use them as ignition improvers for alcohol is that although much used in increasing the cetane number of ordinary fossil diesel oil, they are less suitable in alcohol because of the problem of autocatalytic hydrolysis in the presence of water, under formation of free nitric acid and the constituent alcohol.

Because of the problems associated with using ordinary nitric organic esters as ignition improving substances in fuel alcohol, other options have been searched for in the Swedish projects. It has then been important to avoid nitrogen organic compounds, which may decompose under the formation of nitric acid, what would render the alcohol fuel acid and, subsequently, more corrosive. It was, therefore, an important achievement that the nitrogen-free compound “Beraid” could be developed and tested in the Swedish alcohol fuel projects. The advent of that option coincided also with the disappearance from the market of the substance “Avocet”, which had so far been tested in European bus fuel projects.

Therefore, it was possible to continue the Swedish bus fuel projects while other similar projects had to be closed down in other European countries (like in France and Holland).

However, the use of Beraid as ignition improver for alcohol CI fuel is unsatisfactory on other grounds. Besides being rather expensive (it increases the ethanol fuel price by some 20%) it is based on non-renewable materials and does not, accordingly, contribute to the abatement of the greenhouse gas effect. Further, in remembrance of the fate on the market of the compound "Avocet", it seems to be somewhat risky to rely on a substance, which could be abandoned by its producer on grounds, which would be unacceptable for those who are concerned with the development of alternative, renewable alcohol fuels for heavy duty engines and vehicles. Therefore, the idea of using RME as ignition enhancer was proposed during the implementation of the earlier Esterol I project (ref. 1), in which the benefits of blending RME with ethanol for use as fuel in ordinary, non-dedicated CI engines was investigated.

The development and testing of RME (or, more generally, FAME), as an ignition enhancer for neat alcohol fuels will also feature further advantages. Accordingly, in contrast to the well-known case of 'Avocet' mentioned here-above, which disappeared suddenly from the market leaving the neat ethanol fuel test fleets in Europe without any other alternative than to close down test operations, RME will always be available as long as European agriculture will continue to grow rape. The supply of ignition improvers for neat alcohol diesel fuel formulations would therefore become far less vulnerable and more sustainable with RME than with other alternatives, which would depend too much on, possibly negative, business strategic decisions by the producers of pertinent chemicals.

In spite of all the development and research work having been carried through in regard of the so-called biofuels confirming the environmentally more benign nature of such fuels featuring renewability, it has been remarkably difficult to commercialise such fuels. The principal reasons for this circumstance are that biofuels have been, so far, uneconomic in the present context featuring no possibility to internalise so far external costs for the environment and health as caused by pollution from traffic. It is, therefore, of great importance still to continue developing the biofuels in order to lower the costs of utilisation, thus narrowing the existing price gap to the conventional, fossil fuels.

The objectives of the so-called 'Esterol Project' (ref. 1) have been to *develop and test a blend between RME and ethanol in order to create a fuel formula featuring the potential to lower noxious exhaust emissions due to heavy traffic so typical for our big cities in Europe.* Combining RME and ethanol would, according to reasonable expectations, make it possible to create a diesel fuel formula featuring the potential to combine the good properties of both fuel components while alleviating, partly or totally, the disadvantages as featured by both neat fuel components. So far, the now finished Esterol Project has, largely, confirmed such expectations (ref. 1).

The Esterol fuel concept could also be extended, it was proposed, to include a fuel formula for *ethanol as principal component* in a more environmentally benign diesel fuel. In such a case the *RME component would serve as an ignition improver for the bioethanol to increase the propensity for ethanol to ignite at the conditions created in the combustion chamber in dedicated ethanol diesel engines (featuring increased compression ratios).* An *"Esterol formula" for neat ethanol diesel fuel* could then have a *cost advantage* over the neat ethanol formulas as presently used in the ethanol fuelled vehicles presently running in e g Sweden. *The price gap between conventional, fossil diesel fuel and the renewable options* *would then become narrower,* what would help improving the possibilities to commercialise biofuels in Europe.

1.1 Scope and objectives

The principal objectives of the present project are to develop and to demonstrate the possibility to use RME as a low cost ignition improver in ethanol fuel as used in dedicated ethanol engines (e g as featured by some city buses in Sweden). Various compositions of fuel containing RME and ethanol ('Esterol-X', with 50%<X<90% ethanol) were to be tested and investigated (Project phase I) at Luleå Technical University ("LuTU") as fuel for the high compression ethanol diesel engines. The intention has been to find the optimum fuel composition in regard of cold start properties and drivability and also in regard of exhaust gas emissions of regulated noxious components (CO, HC, NO_x and particles).

One or several ethanol city buses in, e g, someone or in all of the towns of Örnsköldsvik, Luleå and Stockholm were to be field tested on the optimum fuel formula as determined in Phase I of the Project, in regular city traffic during a period of at least 6 months (Stockholm is the principal place for the use of ethanol as an environmentally more benign fuel for public transport buses. Over 50% of the inner city buses there, now in operation, are presently fuelled by ethanol since the start of demonstration tests in 1990. The town of Örnsköldsvik has, however, pioneered the use of ethanol fuel for city buses in Sweden. It began already back in 1985 with a two-demonstration bus test, the success of which can be said to have been a prerequisite for the much larger Stockholm trial. The test buses are all equipped with dedicated Scania, high compression ethanol engines). Reports about these field tests are to be found in ref. 2 and 3.

The scope of the Project also includes Project management featuring monitoring of progress in regard of engine maintenance, consumption of fuel and lubricant oil, analysis of fuel and lubricant etc. The project would, furthermore, be duly reported as one part of the Esterol project to the project parties.

1.2 Actions to be taken:

The technical program of the present project includes six parts as follows:

I: Trying out various fuel compositions of Esterol-X, with the component 'X' (Ethanol) varying up to some 90% using a high compression diesel engine in bench. The optimum X-value to be selected using e g exhaust gas emission criteria. The work to be carried out in co-operation with the Technical University of Luleå, Sweden.

II: More complete characterisation and analysis of the exhaust gas emissions using that fuel formula, that could be selected under point I hereabove. The work to be done at Luleå University.

III: A city bus in one or more of the towns now using ethanol fuelled buses (e g in Örnsköldsvik, Luleå or Stockholm, Sweden), to be tested in regular city duty using the fuel formula optimum as determined under points I and II here above. Pilot buses to be tested during at least some 6 months, after which evaluations and reporting will follow.

IV: Optimisation of engine setting for the fuel formula Esterol-20 as intended for ordinary, non-dedicated diesel engines. Minimum exhaust gas emission levels as selection criteria. This part of the program was to be seen as a rest of the earlier Esterol project (ref. 1).

V: Exhaust gas emission characterisation and analysis for the dedicated ethanol diesel bus (as tested on Esterol-X fuel) may be carried through. Chassi dynamometer testing.

VI: Fuel analyses to be performed in regard of specific fuel variables like density, viscosity, flame point, cold temperature properties, cetane numbers etc. Lube oil analysis program to be performed.

Task IV of the program has been elaborated on as a part of the Esterol Project under the previous contract (XVII/4.1030/Z/96-078), of which the present project is an extension. This work has been reported in the final report of said first Esterol Project (see chapter 3.2.2 of the report, ref. 1).

1.3 Expected results:

Results to be expected from the implementation of the project are the following:

- A new and cheaper fuel formula for ethanol fuel as intended for dedicated, high compression, ethanol diesel engines.
- Improved diesel fuel properties in regard of lubricity and viscosity as caused by the inclusion of an esterified vegetable oil methyl ester as ignition improver (instead of using other chemical additives like Beraid, or nitrate esters, which all have been shown to be featured by some particular negative effects in previous field testing of neat ethanol diesel fuels in Sweden).
- Exhaust gas emission levels, which are significantly lower than those of neat RME and diesel EC1 (Environmental Class I fuel) and similar to those of neat Ethanol fuel presently used in Swedish field tests.
- Optimisation of engine settings for Esterol-20 fuel in regard of exhaust gas emissions. (Esterol-20 fuel containing 20% ethanol and 80% RME is intended for non-dedicated, normal compression diesel engines. This part of the technical program is a direct extension of the Esterol Project).

2 Use of ethanol and ethanol fuel blends as fuel for CI engines.

Neat ethanol has been tested in Sweden as fuel for heavy-duty vehicles since 1985 as part of governmental programs for biofuels. The scale of these tests has grown considerably since the start and they include, presently, the operation of more than 400 buses in inner city public transport duty mainly in Stockholm but also in other cities and smaller towns on the countryside. Furthermore, operation of distribution of goods by ethanol driven trucks in inner city areas has also been demonstrated as additions to the program and, also, blends between ethanol and gas oil. Such blends have been possible due to the advent of a newly invented detergent material with the capacity to make emulsions between gas oil and hydrous ethanol stable up to rather high ethanol contents. This enables the bioethanol option for more environmentally benign duty fleet operation to be expanded for use in geographically larger areas. Non-captive utilisation may then also be contemplated, what is a result of the attainment of complete substitutionality between gas oil and the ethanol blended, emulsion fuel in present-day, ordinary compression ignition engines.

The ethanol/gas oil blend ("Diesohol") option can easily be improved (in some respects such as greenhouse gas emissions) by the Esterol-X concept featuring X=10-30% of ethanol and 90-70% of RME. The Esterol Project (ref. 1) has demonstrated this, during which the heavy-duty vehicles being field-tested were shown to be able to use also fossil diesel oil interchangeably with Esterol-20 fuel. It was even possible to have some gas oil mixed with the Esterol blend, thereby enabling complete interchangability between conventional fossil gas oil driving and driving on Esterol.

The results from the Swedish fleet testing of, in particular, the neat ethanol option as a more environmentally benign (than the ordinary and improved gas oil option including the latest and most modern engine designs) fuel have been satisfactory as to the exhaust emission improvements and, also, in respect of drivability. Accordingly, it has been proven possible to substantially decrease emissions of all "regulated" emission components of the exhausts and, further, also of most unregulated emissions like PAH and aldehydes. This has, certainly, been facilitated by the ease by which it has been possible to apply two-way, oxidative catalysts to the exhausts as "afterburners" (due mainly to the soot particle-free nature of the ethanol fuel exhausts). The potential of the neat bioethanol approach as to greenhouse gas emissions (fossil-based CO_2) is complete alleviation.

The main disadvantage of using neat ethanol as diesel fuel is, certainly, the price of the fuel, which is about doubled as compared with gas oil (accounting for the lower energy content of ethanol than for the conventional, fossil diesel oil (1,7 litre of ethanol is energy equivalent with 1 litre of diesel oil). Further, it is necessary either to use dedicated engine constructions (for instance glow plugs) or to add cetane improvers to the fuel and, also, preferably to increase the compression ratio of the engine in order to create conditions favourable for the fuel to ignite. These features of the ethanol option have proved to create substantial cost obstacles for the acceptance of the ethanol option for heavy-duty vehicles.

The price of ethanol diesel fuel is composed of the price of ethanol (usually in the azeotropic form), the price of the ignition improver substance (a substance called Beraid, which is a derivative of polyethylenglycol and which is being produced by Akzo Nobel in Stenungsund, Sweden) and of the costs for blending, storage and distribution. Choosing RME as ignition improver substance would cut the costs for blending and would also allow adding several times more of RME than of Beraid to obtain the needed ignition quality of the fuel formula.

The Swedish biofuel program has been extensively documented in a large number of reports (most of them in Swedish) and, also, at international conferences. A comprehensive, summarising account is given in the report "Rena fordon med biodrivmedel" from the Swedish Transport and Communications Research Board (ref. 4). A brief account in English of the Swedish biofuels program was provided by Mr Sören Bucksch at the 1997 international conference in Stockholm on the "Use of Biofuels for Transportation". The proceedings from that conference (ref. 5) also include accounts of biofuel programs for other nations, both European and others.

3. Project phases I and II.

The principal objective for work in phase I has been to determine the best possible fuel formula with RME as ignition improver (cetane booster component) to make a dedicated ethanol engine run satisfactorily, equal or better than running on the "conventional" ethanol fuel formulation so far used in pilot tests with heavy duty diesel vehicles.

The principal objective of the work in phase II has been to confirm expectations of the environmentally benign nature of the new fuel formulation as determined in project phase I. Comparisons to be made with the conventional fuel and, also, with EURO 2-4 regulations.

The intention of project phases I and II has then been to carry through, if possible, the work program as listed here below.

- ➢ Investigation of blends of Esterol-X, X to mean percentage of ethanol and to vary between 50 and 90 %. (azeotropic) ethanol. The balance, (100-X)%, to be RME). Appearance and cold temperature stability to be determined and, furthermore, also developed.
- ➢ If possible, determination of the cetane number of Esterol-X as function of the RME contents. Fuel ethanol according to the "Beraid formula" to be used as reference. These measurements to be undertaken in order to get a first indication of which composition will best emulate the Beraid formula.
- ➢ Determination of other pertinent fuel parameters like viscosity, density, Cold Filter Plugging Point (CFPP), etc as function of the RME content.
- ➢ Determination (at LuTU) of power output versus engine speed, the cold start properties of Esterol-X fuel, and 13 mode testing including ECE R49 test cycle. The same program to be carried through for the ethanol fuel so far used - the Ethanol/Beraid formula - as reference case. Selection of the optimum blend of Esterol-X.
- ➢ Characterisation of the exhaust gas emissions in regard of the regulated, noxious components, i e CO, NO_x and HC. White smoke to be determined at cold start up of engine (if possible).
- ➢ In order to enable conclusions about the ignition propensity of the selected, optimum fuel composition, measurements of the cylinder pressures at various loads and engine speeds to be undertaken. Such measurements to be carried through both for the optimum Esterol-X blend and, also, for the Ethanol/Beraid formula as reference fuel.
- ➢ Analysis of the noise emissions will be included in the 13 mode tests.

3.1 Implementation of project work according to phase I.

3.1.1 Prerequisites

The engine, which has been used in the tests, is, as has been indicated here above, a Scania diesel engine, dedicated for Ethanol fuel use. This engine has been developed for use within the framework of the Swedish biofuel program as implemented by the State Authority "KFB" (Swedish Transport and Communications Research Board). When being used in heavy duty vehicles such as for public transport purposes, they are also equipped with oxidation catalysts, which have been developed so as to minimise the exhaust gas emissions of CO, HC, NO_x, aldehydes, particulate matter, etc.

The ethanol engine (11 litres) is characterised as follows:

- ♦ Compression ratio: 24:1
- ♦ Power: 191 kWh at 2000 rpm
- ♦ Intercooler
- ♦ Turbocharging

The Ethanol buses in regular duty in Sweden (there are some 400 such buses now in operation in a number of cities and towns) have been comprehensively tested in regard of the exhaust gas emission characteristics.

The fuel, which, so far, has been used for the dedicated, Scania ethanol engine for the ethanol buses, is featured by the following formula:

- Ethanol (Azeotropic quality): 92 vol.-%
- Ethanol denaturants: 3 "-
- Ignition improver (trade mark: "Beraid"): 5 "-
- Corrosion inhibitor: 250 ppm
- Colour marking by a red dye: 5 ppm

The ethanol bus fleet using this fuel formulation and operating in regular, daily duty in Sweden constitute, probably, the world's most extensively and completely tested bus fleet. No effort has been saved in order to alleviate any doubts whatsoever regarding the superior exhaust emission characteristics of these buses. Accordingly, regulated as well as many non-regulated components of the exhausts have been subject to careful analyses and assessments at the Swedish national institute (MTC in Haninge, south of Stockholm) for measuring engine exhaust emissions of all kinds. Test methods like the ECE R49 cycle and the so-called Braunschweig stochastic bus cycle, simulating real world driving conditions, have been used. The results are spectacularly good as are demonstrated as follows (ref. 4: KFB report NR 1998:2):

Test cycle	NO_x	CO	HC	Part.
ECER49 (g/kWh)	3,8	0,05	0,16	n a
Braunschweig (g/km)	6,5	0,16	0,14	0,04

Note: 'n a' means 'not analysed'

These values can now be compared with the Euro 2 requirements for the indicated exhaust emission components (test cycle ECE R49, g/kWh). The emulation is obvious:

- NO_x : 7,0
- CO: 4,0
- HC: 1,1
- Part: 0,015

The exhaust gas emission values as of the table here above, should now be emulated by the new fuel formula, Esterol-X, with the optimal X-value to be determined in present phase I and II work. The principal fuel formula is the following:

- Ethanol (azeotropic and denatured): X vol.-%
- RME (additivated): (100-X) vol.-%
- Corrosion inhibitor: 250 ppm

The test program at Luleå Technical University was ordered to be carried through during the autumn of 1999. The implementation of the work was, however, delayed, unexpectedly, partly due to installation of new equipment and methods at the engine laboratory. Information about the engine laboratory at Luleå Technical University is provided in Annex 3 to this report.

The results of the investigations are presented here below.

3.1.2 Phase I work at Luleå Technical University (LuTU):

Prior to the work at LuTU various Esterol fuel compositions were analysed in regard of important fuel properties (kinematic viscosity at 40 °C, cold filter plugging point, CFPP, cetane NR) with results as of table 1.

It appeared during these measurements, that it was not possible to determine the cetane numbers of Beraid fuel or of Esterol-60 and -80 by using an ordinary CFR engine. The reasons being that this engine is dedicated for analysis of hydrocarbon fuels and the like (like neat RME) as featured by high and moderately high cetane numbers (low cetane fuels can not be analysed in the CFR engine).

However, important information about the ignition characteristics of low cetane, Esterol fuels (and, also, of "Ethanol/Beraid fuel") can be obtained by studying cylinder pressure pulses following fuel injection and ignition. The program for fuel characterisation included, therefore, such measurements (se below). The interest for including combustion cylinder pressure measurements was, also, due to the fact that the heat values of the Esterol fuel blends being used in the present investigation differed somewhat from that of the reference fuel ("Beraid fuel"). Accordingly, the heat values of the Esterol fuel blends as studied were about 5 - 10% higher than that of the reference fuel. Therefore, leaving the fuel injection pump without adaptation to the higher heat content, one could expect the cylinder pressure following ignition to be higher than that of the reference fuel.

Table 1: Fuel parameters of various motor fuels (measurements performed at SGS Svenska AB in Gothenburg).

Fuel comp.	Viscosity (mm^2/s)	CFPP (°C)	Cetane NR
RME	4,439	-10	54,8
"Beraid"	1,405	<-40	nd
Esterol-80	1,282	-12	nd
Esterol-60	1,632	-10	nd

Note: "Beraid" means the "conventional" ethanol fuel formula so far used in Sweden with 5 vol.-% of Beraid as cetane improver. Esterol-80 and 60 means ethanol fuels with, respectively, 80 and 60 vol.-% of azeotropic ethanol and 20 and 40 vol.-% of RME.

The kinematic viscosity of the Esterol fuels analysed seems to be somewhat lower than that of "Beraid ethanol" fuel. It is, however, highly probable that the lubricating properties of an Esterol fuel would be better than those of Beraid ethanol fuel due to the excellent lubricating properties of neat RME, what should add to the quality of Esterol fuel formulations.

The CFPP point values as obtained seem to indicate a need for improving the winter properties of Esterol fuels, especially for Northern European climatic conditions. This problem can be handled successfully, however, by using conventional "winterising" chemicals during winter times. Development work has, also, been included in the technical program of the phase I work in order to obtain improvements in this important respect. The results from the work show that the cold temperature behaviour of the Esterol fuel formulations can be improved considerably by adding small amounts of suitable chemical compounds like metacrylic acid esters making the Esterol fuels suitable down to –25 °C (and even lower).

3.1.2.1 The technical program carried out at LuTU.

The technical feasibility of RME as ignition enhancer for neat ethanol fuel was studied by implementing the following technical program at LuTU:

- Determination of the cold start properties and of the engine power at various blends of RME and ethanol.
- Opacity measurements during the cold start-up process. The start-up procedure followed the following scheme:
  - Cold starting at ambient temperature.
  - Idling during 2 minutes
  - Power increase up to 1100 rpm/550 Nm; 5 minutes driving.
- Drivability testing of the ethanol-dedicated Scania diesel engine with various Esterol fuel blends and, also, with the Ethanol/Beraid fuel formula. Test method used according to a reduced 13-mode test and, also, according to the ECE R49 method.
- Analysis and characterisation of regulated exhaust gas emission components like CO, NO_x, and HC. Method: ECE R49, 13-mode test.

It soon appeared that the efficiency of RME as ignition improving additive to ethanol was considerably higher than expected, what made it unnecessary to test fuel compositions with RME contents higher than 25% (for the particular test engine used). Esterol-X fuels featuring 75<X<90 were then analysed regarding their respective fuel properties. Another principal reason for the decision not to include higher RME contents in the Esterol fuel blends, was that the heat values of blends with more than 25% of RME would augment the heat value of the blend too much with an ensuing risk to exceed certain engine design limits as determined by the engine manufacturer (Scania).

3.1.2.2 Engine power measurements and cold start properties of Esterol.

The results obtained indicated, that it was difficult to start the ethanol engine for Esterol-X fuels with X>84. As can be concluded from power curve diagrams below, cold starting of the engine was, however, just possible for Esterol-84 (i e for 16% RME in ethanol; diagram 1 below) fuel. The engine started well with this fuel formulation and ran without problems at higher loads and engine speeds. The condition for cold start of the test engine is then that the Esterol fuel blend must contain more than about 16% of RME (of the RME qualitiy as used. Other qualities may show other results). Further, diagram 2 reveals that the engine power becomes higher for the Esterol fuels with decreasing X, i e with more RME. With fuel injection volumes held constant, the power output then increases by some 5-10% for the blend compositions as examined.

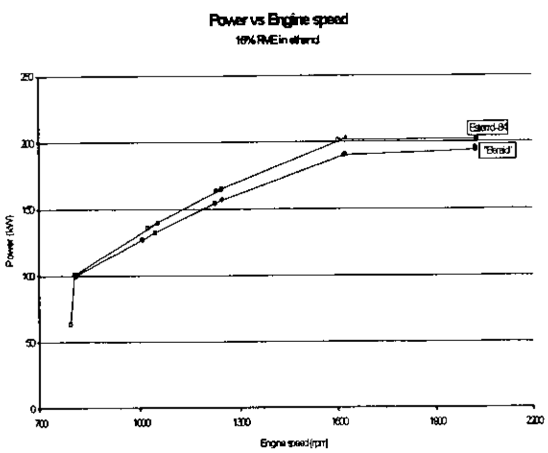


Diagram 1

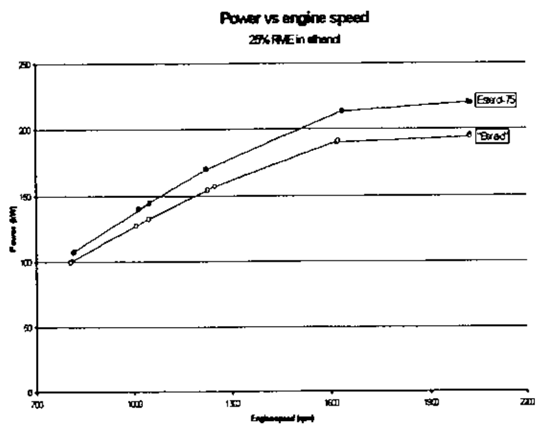


Diagram 2

The cold start testing was then carried through for all of the Esterol blends of interest for the project. The "conventional" Ethanol/Beraid fuel was used as reference. The following procedure was used:

- 2 minutes of idling after ignition
- 5 minutes of driving at 1100 rpm and with 550 Nm load.

The results obtained are summarised in diagram 3, Annex 1, from which can be concluded that the engine operated very well and smoothly for the Esterol fuel blend of preference (Esterol A). It can also be observed from the diagrams of Annex 1 that the engine operation grew better and better by increasing the RME content. It may even be possible to conclude from diagram 3 that the cold start properties seem to be even better for Esterol fuels than for the "conventional" Ethanol fuel using Beraid as ignition improver. Accordingly, curves for the HC and opacity measurements reveal that use of Ethanol/Beraid fuel is associated with the appearance of peak emissions just at start up and after 30 seconds following a stable, idling period, which is followed by a stepwise increase of both speed and torque. Use of Esterol A fuel is not accompanied by such peak emissions.

Further, the emission of white smoke (small droplets of unburned RME fuel) at cold start was proven to be rather insignificant at ambient conditions, although it appeared to be higher than that for Beraid ethanol fuel. If a problem, it may be remedied following change of fuel injection and of increasing the efficiency of the exhaust gas catalyst equipment. The smoke measurements were performed by using new, separate HC equipment, which was installed for meeting the demand for such measurements from the Project.

The emission of small droplets (particles) of RME may have harmful health effects just as the emission of small particles from any ordinary, fossil diesel fuel. It is important, however, to note that the RME droplets consist of pure organic materials, which make them more combustible on the catalyst's heated surface than particles from ordinary diesel fuel of fossil origin. The literature has, also, indicated that the particular and unusual smell of RME exhaust gases constitutes a hindrance for good market penetration of vegetable oils as motor fuels. It is, therefore, advantageous to note that white smoke emission is, most probably and according to the present results obtained, not a crucial problem for Esterol-X fuels with X larger than 75 (%). Increasing the efficiency of the exhaust gas catalyst equipment could diminish this emission considerably. In particular, catalytic converters, based on metal substrates, from e g Oberland Mangold, Germany, seem to feature high efficiencies in regard of HC and particulate emissions from RME fuel use (Annex 2).

The smoke measurements were performed by using new, separate HC equipment, which was installed for meeting the demand for such measurements from the Project.

3.2 Phase II work at Luleå Technical University.

3.2.1 Measurements of the combustion cylinder pressure.

As mentioned above, it was of interest also to carry through measurements of the combustion pressure pulses following fuel ignition. Such measeurements were, accordingly, implemented for various engine speeds and loads. The measurement device is depicted in some detail in Annexes 3 and 4.

The combustion pressure pulses were, accordingly, measured at 10% load for two engine speeds, 800 and 1300 rpm respectively and for all the various fuel blends to be compared. It appears that all fuel blends give rise to very similar pressure pulses at combustion. It is also obvious that the maximum pressures are

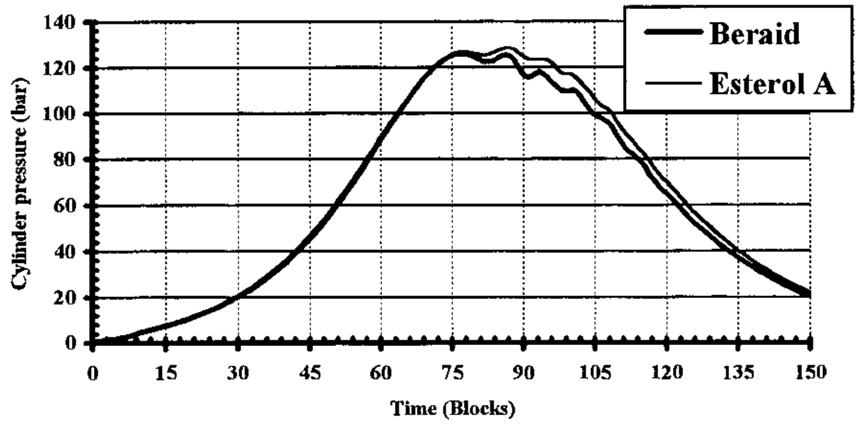


Figure 1: Combustion pressure pulse for 90 % load and 1800 rpm

about the same and do not corroborate fears of excessive cylinder pressures for the Esterol fuel blends in comparison with the pressure effect of using the reference fuel (Beraid/ethanol fuel).

The combustion pressure pulse obtained at higher loads would, however, be more significant. Therefore, a cylinder pressure curve was obtained for 60 and, also, for 90% load and for the engine speed of 1800 rpm. Judging from the pressure pulse curve of figure 1 above, depicting the pressure effects at 90 % load, no excessively high cylinder pressures are appearing.

Further, from the pressure pulse curve of fig. 2 below, it is also possible to deduce that the combustion starts at some 2 degrees crank angle earlier for Esterol A than for the reference fuel containing Beraid as ignition improver. It may follow from this, that it would be possible to decrease the content of RME as ignition enhancer in ethanol diesel fuel for dedicated, high compression engines. Further development work would then be needed in order to achieve at the optimal Esterol fuel composition, what would also have a positive impact on the market price of the fuel.

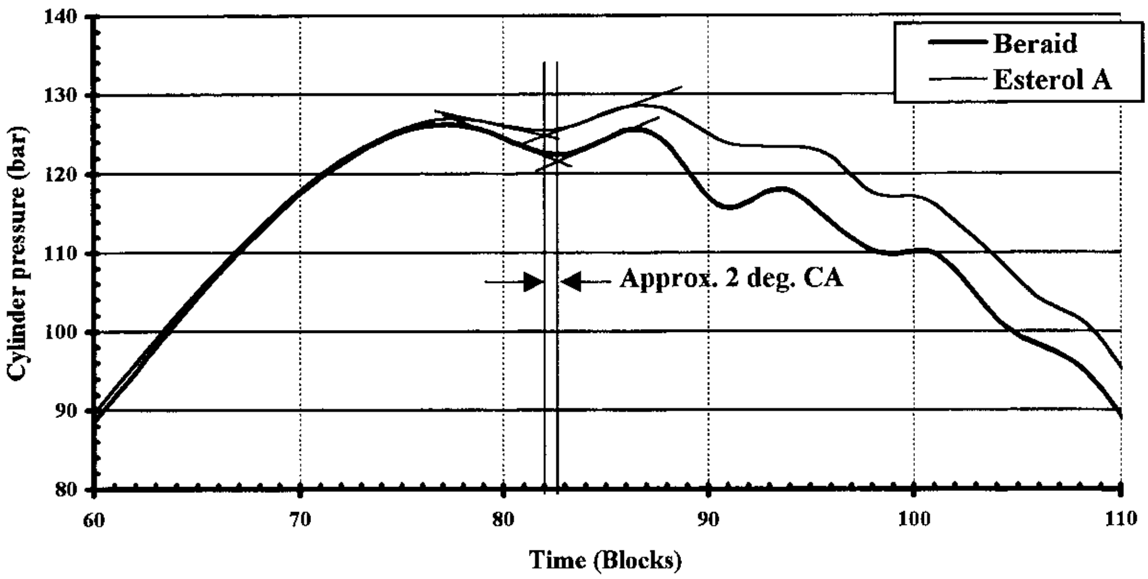


Figure 2: Deduction of the onset of ignition in the combustion chamber.

3.2.2 Engine noise measurements.

The scope of the research and development work at the Luleå Technical University also includes investigations on noise emissions from the vehicles (cf. Annex 3). Accordingly, noise measurements have been carried through also for the Scania test engine while being driven on neat ethanol fuel containing either RME or Beraid as ignition enhancers. Table 2 depicts the results, from which is clear that the differences between Beraid and RME as ignition improvers are insignificant in regard of noise emissions. Imperfect ignition of the Esterol fuels in the engine would have been revealed as increased noise emissions. As the results of table 2 do not indicate any such phenomenon, the conclusion is that all of the Esterol fuel formulations as tried performing just as well as the conventional Beraid formula.

Table 2: Noise emissions dB (A).

Engine speed	800 rpm			1300 rpm			1800 rpm		
Noise level dB(A)		dB(A)			dB(A)			dB(A)	
Load	10%	50%	90%	10%	50%	90%	10%	50%	90%
Ignition improver*									
"Beraid" (ref)	95.39	94	93.11	96.36	96.44	98.82	99.49	100.1	102.4
X_1% RME	94.47	93.59	93.13	97.77	97.41	98.59	99.98	101.5	102.7
X_2 % RME	94.13	92.89	92.25	96.36	96.44	98.82	99.49	100.1	102.4
X_3 % RME	94.12	93.28	93.02	97.65	97.08	98.35	99.64	101.2	102.4

* The nominal percentage of RME in ethanol is priority information and not revealed here.

3.2.3 Exhaust gas emission characterisation and analysis.

In view of the results of the phase I work at LuTU and of the combustion pressure measurements as depicted above, it appears possible to use an Esterol fuel formula with a rather small content of RME as ignition improver in fuel ethanol for the dedicated ethanol diesel engine used for testing. It is even conceivable that it would be possible to lower the RME content still further by screening the RME component for maximum cetane numbers (there are Fatty Acid Methyl Esters, "FAME", available and which feature cetane numbers in the range 60 - 70 (or even higher) to be compared with CN 53 for the RME being used in the present experiment). Selecting an Esterol fuel formula with a minimum amount of RME would, further, minimise possible stressing of the design limits for the combustion pressure. The combustion cylinder measurements performed seem to indicate that the maximum cylinder pressure increase would not exceed some 5 % for fuel formulas containing up to 20% of RME. The final selection of the optimal fuel ethanol formula should, however, take account also of the exhaust emission characteristics of the Esterol formulations.

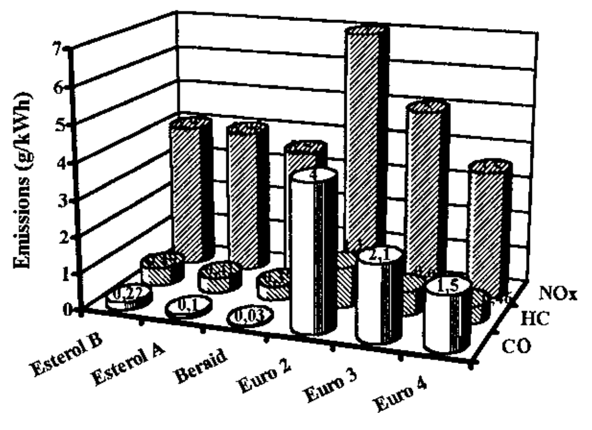


Fig.3: ECE R49, 13-mode exhaust gas emissions for neat ethanol fuels as compared with EURO 2-4 requirements.

The exhaust gas emissions were, accordingly, characterised and analysed for the selected fuel formulations in regard of the regulated components (CO, HC and NO_x) by using the ECE R49 fuel test cycle. Comparisons could then be undertaken with the exhaust gas emission properties of the "conventional" Beraid/ethanol fuel and compared also with the requirements according to Euro 2, 3 and 4. As is obvious from figure 3 here below, these comparisons indicate confirmations of the expected good emulation properties of the Esterol fuel formulations as chosen.

It appears from these measurements that the exhaust gas emissions from the use of the two Esterol fuel formulations both are almost as good as those of the "conventional" ethanol/-Beraid formulation. It is conceivable, however, that this comparison would be further improved for the Esterol fuel formulations by choosing engine settings, which are optimal in regard of the Esterol requirements as determined by the combustion properties of such fuel. In the present context, it should not to be forgotten, that the comparisons have so far been undertaken with the neat ethanol test engine being optimised for "Beraid/ethanol" fuel to the (possible) disadvantage of the Esterol fuel formulations.

Further, it is obvious that the Esterol fuel formulations Esterol A and Esterol B will easily emulate the Euro 2 requirements. Even future, pending requirements according to Euro 3 and 4 could successfully be emulated by the new fuel formulations of Esterol A and B. The exhaust gas emission results so far obtained are also given in table 3 here-below.

Table 3. Exhaust gas emissions according to the ECE R49 fuel test cycle.

Fuel/req.	CO	HC	NO_x
Esterol B	0,243	0,525	3,971
Esterol A	0,148	0,426	3,946
"Beraid"	0,05	0,16	3,8
Euro 2	4	1,1	7
Euro 3*	2,1	0,66	5
Euro 4*	1,5	0,46	3,5

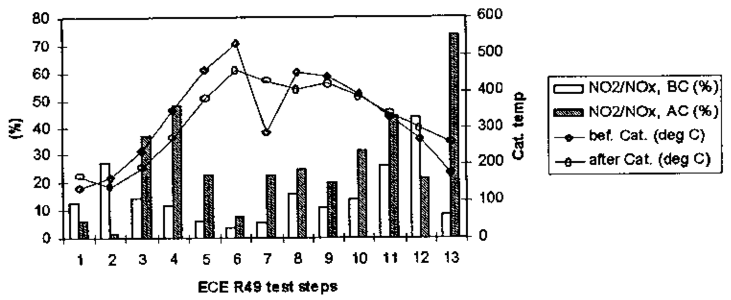
- Pending, future European requirements

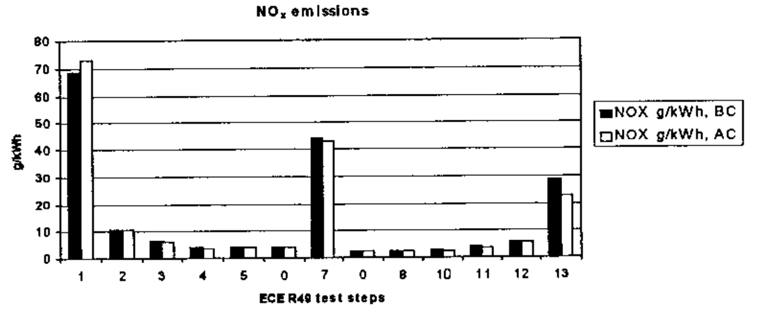
3.2.4 Exhaust gas after-treatment by use of an oxidising catalytic converter.

Use of biofuels make it possible to apply exhaust gas after-treatment by use of catalytic converters, which then serve as oxidisers for combustible exhaust gas components such as CO and HC. Due to the fact that biofuels do not contain inorganic materials, there is low risk for catalyst poisoning or catalyst clogging, what will extend the effective life of the catalysts.

In the present case a catalyst, featuring ceramic material, was used, which had been delivered as an integral part of the ethanol engine from Scania ("Scania Eberspächer, PTX P 9904 AC4623"). That particular type of catalyst is, furthermore, also equipping a large part of the ethanol buses in Sweden. The efficiency of the catalytic converter is obvious from the diagrams below. Accordingly, HC and CO can be effectively oxidised to about 90 %. Therefore, a prerequisite for the excellent results as obtained and depicted above (Fig 3) is the application of an efficient catalytic converter. The type of oxidative exhaust gas converter as used is also an effective aldehyde oxidiser, what has been proven earlier during implementation of the very comprehensive program for characterisation of the exhaust gas emissions from the ethanol test buses in Stockholm (ref. 3).

On the other hand, however, Nitrogen monoxide undergoes oxidation to Nitrogen dioxide, i e NO to NO_2, to some extent as is seen from the diagram below, which depicts the ratio NO_2/NO_x in the exhaust gas emissions as obtained at the various load steps of the test cycle ECE R49. The temperature at each individual ECE R49 test step was measured before and after the catalyst converter ('BC' and 'AC' respectively in the diagram) during testing. By superimposing the measured temperatures 'BC' and 'AC' in the bar diagram depicting the ratio NO_2/NO_x at the 13 different steps of the test cycle ECE R49, one can briefly follow how the equilibrium between NO





and NO_2 is shifting, while varying the temperature of the exhaust gases. The shift from NO to NO_2 and back occurs in accordance with the chemical oxidation/ reduction formula:

$$NO + 1/2\ O_2 = NO_2$$

The conclusion to be drawn from this behaviour of the NO/NO_2 oxidation/reduction process could then be that periods of idling should be minimised during a duty cycle because NO_2 – being the more health effecting of the pair of oxides considered – would then dominate the NO_x emissions at such conditions. It would also be conceivable that the same behaviour would be observed independent of the particular nature of the fuel used.

The HC diagram of similar appearance, confirmed that the catalytic, oxidising converter has been effective in lowering the exhaust gas emission levels of HC (consisting mainly of unburned fuel ethanol). At the ECE R49 test steps No 3-6 and 8-11 the engine loads were sufficiently high to give almost complete fuel combustion so as to minimise the HC level even before the catalyst.

The efficiency of the catalytic oxidiser was, finally, also underlined by the results of the CO measurements showing similar results as for HC.

The total NO_x exhaust gas emissions are, finally, depicted in the NO_x diagram (above) over the different load steps of the ECE R49 13 mode test cycle. It becomes clear from this diagram, that the emissions are much higher at no load (step 1, 7, and 13), which means idling. The same picture would also have been obtained independent of the particular diesel fuel type used for driving. Increasing the load (from step 2 to 6 and from step 12 to 8) is then followed by much decreased NO_x emission levels. Minimising idling conditions for heavy duty transport then seems to be an important measure for the abatement of air pollution from traffic especially in regions of dense traffic in large cities.

4. Project phase III: Field test of the neat ethanol, Esterol fuel formulation.

4.1 Selection of location and company to carry through the field test.

From the results obtained in phase I and II work at Luleå Technical University it was possible to select an optimal Esterol fuel formulation ("Esterol A") for further testing of a neat ethanol fuelled bus in regular public transport duty in the town of Örnsköldsvik. The criteria used for selecting Örnsköldsvik as the location for the field test were the following:

- The bus company in Örnsköldsvik had previously acquired extensive and long-term experience in ethanol driving of public transport city buses. In fact, the town of Örnsköldsvik was the first place in Sweden to join the national efforts to develop and test the ethanol option for more environmentally benign bus fuel. They started back in 1985 and operate now about 70% of its bus fleet on ethanol fuel.

- During their long term involvement in the national biofuel efforts Örnsköldsvik Bus Co. has been involved in the crucially important field testing of the various ethanol fuel ideas, which have successively been suggested during the national development period of biofuels in Sweden.
- Örnsköldsvik is situated about 600 km to the north of Stockholm, what makes it possible to test the fuel in a sufficiently cold climate for the winter properties of the fuel formulation to be revealed and determined.

However, by far the largest field test of ethanol fuelled city buses in Sweden has been going on in Stockholm since April 1990 when the ethanol bus project first started with 32 buses. Following successive developments of the diesel engine as dedicated to fuel ethanol the engine and bus manufacturer (Scania) was, by then, ready to endorse expansion of the tests from the small demonstration scale size in Örnsköldsvik up to a size, which could allow the acquisition of better and more conclusive statistics in regard of the environmental benefits of bus driving on bioethanol as compared with conventional driving on petrol diesel. In so doing, the bus manufacturer responded positively to meet public and official demands for environmental improvements in the inner, city area of the Swedish Capital.

The experience and results from the first 32-bus project in Stockholm were good and convincing enough to allow the ethanol bus project to expand even further up to the present scale of some 250 buses. The ethanol option for more environmentally benign transport fuel for heavy-duty vehicles has simultaneously been expended to several other towns in Sweden. The total number of buses in the different pilot bus projects amounts, accordingly, at present to some 400 buses, which all have been manufactured by Scania and which are fuelled by the same ethanol fuel formulation. This formulation has been changed once during the implementation of the projects mainly due to cessation of production and sales, by ICI Chemicals Ltd, of one fuel component of crucial importance (namely the ignition improving substance "Avocet", which contains a nearly explosive compound with the effect to increase the propensity for the principal fuel component ethanol to ignite in the CI engine). Following the experiences and results as obtained from the first, original bus demonstration project in Örnsköldsvik, a nitrate-free product could replace Avocet, "Beraid", which is derived from ethylene oxide and domestically produced. Thereby the entire fuel ethanol program for heavy-duty vehicles in Sweden could be saved and the threat of its immediate termination due to lack of an efficient ignition improving substance for an adequate fuel formulation could be avoided. In contrast, other European projects for field testing of neat fuel ethanol for buses outside Sweden could not be sustained due to reasons as indicated.

Due to these experiences and, also, because of the possibility to achieve lower prices of the ethanol bus fuel by substitution of the conventional "Beraid/ethanol" formulation by the new formulation containing RME as ignition enhancer ("Esterol" formula) the bus operating company in Stockholm has indicated interest in the implementation of a pilot project for Esterol fuel. Accordingly, 5 test buses are soon to start operation in Stockholm. This test will be carried through during the winter of 2000/2001 up to about April/May thereby determining the conditions for winter driving on the Esterol fuel formulation.

4.2 Bus and engine for the field-test in Örnsköldsvik.

The ethanol engine (11 litres) of the test bus in Ömsköldsvik is dedicated for ethanol and characterised by the design features as given here below:

- Compression ratio: 24:1
- Power: 191 kWh at 2000 rpm

- Intercooler
- Direct fuel injection
- Turbocharging

The engine is developed and produced (in series) by Scania in Sweden. This engine type ("DSI11 E01") and its successor, a 9-litre version, is equipping all of the ethanol buses in Sweden presently in operation (about 400).

The adaptation of the engine to the properties of the specific ethanol fuel includes changes of the ignition timing, increased fuel pump capacity to allow for the lower heat content of the ethanol fuel formula, wider injector holes, and alcohol resistant materials in the fuel line.

The test bus is a normal city bus featuring some 40-passenger seats (fig 4 below). It is equipped with a catalytic exhaust gas emission converter ("afterburner" of combustible exhaust gas components like CO and HC). The catalyst converter was developed and produced by the company Svenska Emissionsteknik AB, for which the focus was on the achievement of good and efficient abatement of aldehyde emissions (catalyst identity number: "DF28 Etanol"). It has also a very good capacity to reduce the regulated exhaust gas emissions.

The test bus has been in regular city duty since 1988 and has been driven on ethanol fuel during its entire life. It has travelled a total distance of 665 000 km on neat ethanol fuel and is, thereby, one of the heavy duty vehicles, which have travelled the longest distance of all in the world on alcohol fuel formulations. The test bus is, therefore, also of great value when trying to estimate possible engine lifetime changes when exchanging ordinary diesel oil with neat ethanol fuel. Because the test bus has been run on earlier ethanol fuel formulas it may also be possible to make comparisons between the earlier results and the ones being generated by the present project.

Figure 4: The ethanol test bus in Örnsköldsvik. This test bus has been driven exclusively on neat ethanol fuel during its entire life (travelled distance: About 700000 km).

A field test with 5 ethanol test buses is also soon to start in Stockholm. These test buses will be newer buses and 2 of them will be equipped with the successor to the 11 litre engine, namely the 9 litre bus engine version.

4.3 Test fuel.

The test fuel is composed of neat, azeotropic ethanol being supplied by the company Swedish Ethanol Chemistry AB ("SEKAB") in Örnsköldsvik and of RME as supplied by the company Wibax AB in Luleå. The fuel blending has been carried through by the project manager according to a proprietary formula ("Esterol A").

SEKAB is the sole supplier of all ethanol fuel for buses in Sweden since the beginning of the national program for biofuels and has, therefore, acquired extensive and long-term experience of all regulations and intricacies, which are associated with the use and sales of industrial alcohol. The RME component is imported from Germany (from the firm Conneman in Leer).

The specifications for the two principal components (ethanol and RME) of the fuel blend formulation is found in Annex 5.

4.4 Fuel storage and fuel filling.

Neat ethanol fuels belong to the same safety class as gasoline, what has effect on how the fuel can be stored. Over ground storage is, generally not allowed, what affects the design and construction of the storage and filling station for such fuel. It is possible, however, to get allowance to store and handle class 1 fuel over ground on condition that the storage facility includes certain safety measures, which can be deemed adequate and appropriate by the authority in charge.

Accordingly, the storage tank must be double-mantled including a space for the safe and leak-free storage of such fuel quantities, which may have leaked out from the inner tank. Further, the closed mantle space between the two tanks must be monitored for leaks possibly occurring. Finally, all electric equipment must be X-rated.

After the acquisition of all these safety requirements the project succeeded in getting approval from the authorities to use the facility as depicted in fig 5 above. The storage capacity is 15 000 litres.

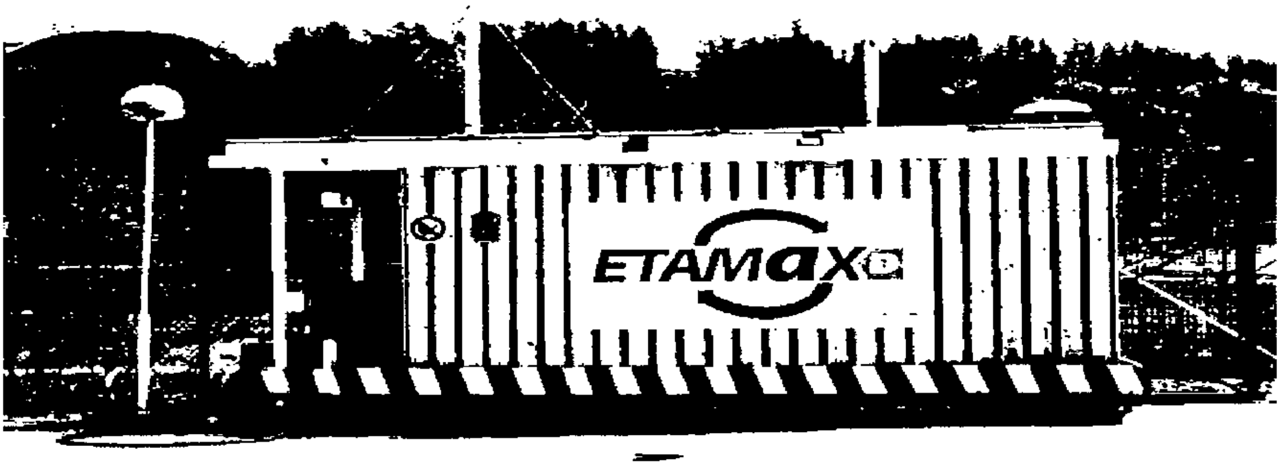


Figure 5: The ethanol tank storage and filling station.

4.5 Results.

The test bus (fig 4) was put in regular traffic duty in the inner city of Örnsköldsvik in May 2000. The fuel consumption since then has been as depicted in figure 6 below. A comparison has been undertaken with existing results from driving the same bus individual on the conventional ethanol/Beraid fuel formula as reference fuel, which has been developed during previous projects in Örnsköldsvik (cf ref 2).

It then appears, that the volumetric fuel consumption is somewhat lower for the Esterol A formulation than for the reference fuel formulation. The average consumption over the six month period of field testing is some 5% lower for Esterol A than for the reference fuel. The comparison is undertaken for the same seasonal period of the year (May to October) in order to avoid temperature and climatic effects as much as possible. In spite of such precautions being undertaken (the same time period of the year, the same bus individual) it must, nevertheless, be admitted that the comparisons are not flawless as the test results from

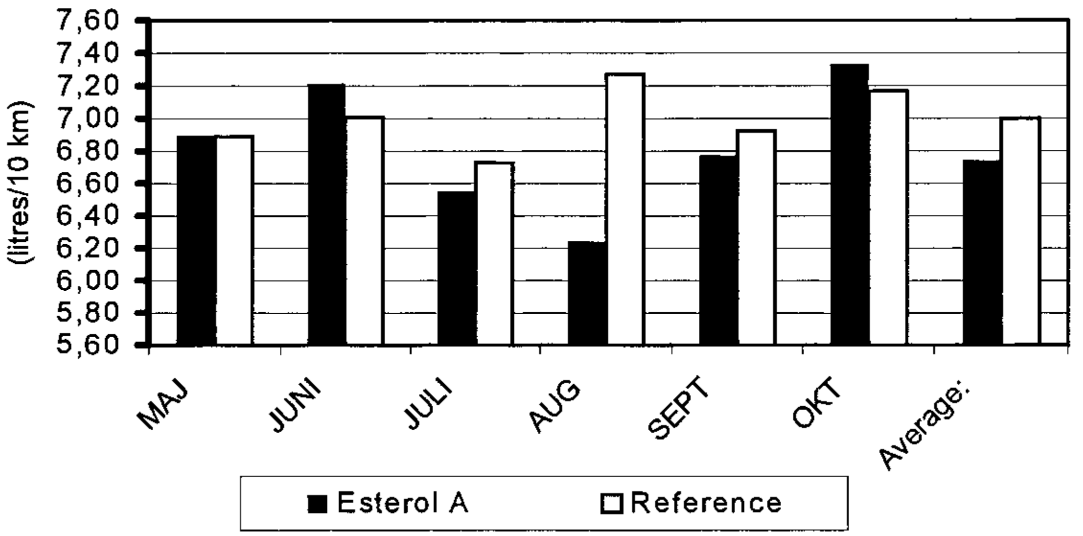


Figure 6: Ethanol fuel consumption by the test bus during project implementation.

previous field tests can not be expected to have been invariant over time. The bus grow older with time what will, conceivably, influence results such as fuel consumption, lube oil analysis, maintenance etc. Figure 6 should, therefore, be interpreted as indicative only and that the observed differences in fuel consumption are to be seen as rather insignificant until more data become available.

The drivability of the bus has been reported to be excellent and without any complaints during the time period so far having been investigated.

The lubrication oil (Mobil Delvac) having been used so far for the ethanol dedicated buses on Beraid fuel has been used also for Esterol A driving without problems. Analysis of used oil after 3 months indicated some in-leakage, namely to about 2% of RME into the lub oil, what, however, has not caused any detectable problems so far. RME has in itself very good lubrication properties and is, accordingly, not expected to cause lubrication problems due to in-leakage into the lub oil.

Cold starting has not been difficult. During the start-up process, the exhaust gas emissions seem, however, to contain more visible smoke as compared with the use of the reference fuel. The explanation is most probably, that RME, in having a high boiling point, is not being completely burned during the first, initial cold start-up phase with the effect that small droplets of RME is being exhausted during start-up. The smoke emission ceases after a short time period following modest heating-up of the engine. This problem, if at all a problem, will most probably not appear during the cold part of the year when the bus engines are being heated by circling hot water (some 70 °C) during the inactive time of the day. Continued field testing during the coming winter will settle the case.

The cold temperature properties of Esterol A fuel have so far not been challenged enough during the project. By extending the project scope to include winter driving these properties will be tested down to about –25 °C.

5. Project phase V: Prospective chassi dynamometer testing of a bus on Esterol A fuel.

It has been the intention to include characterisation and analysis of the exhaust gas emissions from a dedicated ethanol city bus as mounted on a chassi dynamometer in order to enable comparisons to be made with the extensively analysed buses of the very large city ethanol bus project in Stockholm. It was concluded, however, that comparisons between exhaust emission data as obtained by ECE R49 testing would provide sufficient information in regard of possibly occurring differences between Esterol A and the reference fuel (with Beraid as ignition enhancer), especially as all of the different fuel formulas could be tested on the same engine. The results of such testing have been reported here above (chapter 3.2.3, figure 3 and table 3), which reveal almost the same low emission levels for all of the fuel formulations of Esterol A, B and that of the reference fuel (Beraid formula). It is not anticipated that transient testing of the buses on the test and reference fuels would result in different, relative results.

6. Project phase VI: Analysis of fuels and of the lubrication oil.

Fuel analyses has been performed in regard of specific fuel variables like density, viscosity, flame point, cold temperature properties, purity etc. It has not been possible, however, to measure cetane numbers of the ethanol fuels using a CFR engine. The suitability of the Esterol fuel formula for dedicated alcohol engines has been amply proved, however, by the implementation of the project's program as reported in the present report. The results are depicted above in chapter 3.1.2 and in table 1.

Sampling of used oil occurred after 3 months of driving and subsequent analysis for the content of RME having possibly been diluting lubrication oil. The results revealed in-leakage of RME to the extent of about 2 %, what was estimated acceptable, especially as RME features good to excellent lubrication properties in itself. In confirmation of this, no problems seem to have been observed due to such in-leakage of RME in contrast to the lubrication problems having been observed following use of the reference fuel (Beraid/ethanol formulation) in the Stockholm ethanol bus project.

7. Project phase IV: Attempts to optimise engine settings for the formula Esterol-20.

In this part of the program optimisation of the engine settings was intended to be carried through with the objective to enable use of the full, environmental potential of RME as an environmentally more benign diesel fuel, for the fuel formulation of Esterol-20 (20% ethanol in RME). This blend fuel formulation has been proven, in the previously implemented "Esterol Project I" ("EP I"; ref. 1), to be suitable for ordinary CI engines featuring normal compression ratios. The main rationales for the undertaking were focussed on the idea to demonstrate that it should be possible to emulate the performance of ordinary CI engines, especially in regard of the NO_x emissions, as run on either neat RME or on neat EC1 ("Environmental Class 1") fuel. There is, namely, evidence in international work that the exhaust gas characteristics of neat RME fuel really are better than those of ordinary, fossil diesel fuel with the possible exception of the NO_x component of the exhaust gas emissions (ref. 6).

The test engines so far used in implementing the EP I work, featured, accordingly, engine settings, which had been optimised for ordinary diesel fuel (in Sweden: EC1 fuel) instead of for Esterol-20 fuel. It is, therefore, conceivable that any comparisons so far undertaken between neat diesel and neat Esterol-20 fuels in regard of the exhaust gas emissions in general and those of the NO_x emissions in particular have become improperly biased in favour of the neat fossil fuel formulations, thus hiding the true efficiency of the ethanol additive to the RME fuel.

Now, a report of the results from the project work to be undertaken in this phase of the project, could be included already in the final report of EP I (ref. 1) as it appeared feasible to take the opportunity to do so as an extension of EP I work being implemented at VTT, Helsinki, Finland. The two project phases, EP I and EP II, was, accordingly, overlapping each other to some extent.

7.1 Tests at VTT Technical Research Centre of Finland

According to the final report of the EP I project, exhaust gas emission testing were carried out at Volvo Air Turbines ("VAT") in Malmö, Sweden. A normal city bus was used in the tests using a chassis dynamometer and simulating city driving according to a special city driving cycle (ref. 1). By using the same test vehicle with varying fuels ("fuel varying, everything else the same") the measurements enabled comparisons to be made between the different fuels tested.

However, facing a need to enable more generally valid exhaust gas emission comparisons to be established for different fuels, it becomes necessary also to use test methods, which are more internationally well known. Therefore, tests were carried out at VTT, Finland, using the ECE R49 test method. The engine tested satisfied the Euro-II requirements (see below, Table 4). The test program included the following measurements:

- NO_X emissions
- CO emissions
- HC emissions
- Particulate emissions
- Fuel consumption

The exhaust gas emissions were measured and compared for three different fuels, namely

- Esterol-20
- Neat RME
- Neat diesel, Swedish quality EC1 ("Environmental Class I"), meeting the Swedish "Miljöklass 1" requirements (see Appendix 4, ref.1).

The RME fuel component was delivered by Svenska Ecobränsle AB directly to VTT, which company also performed the blending operation on the site for the tests. The ethanol product was of Finnish origin and was supplied by VTT. The EC1 product was taken from VTT in-house stock. All fuel components were satisfying applicable standards and specifications.

The engine data were as given in Table 4.

The Esterol-20 fuel was blended and stored at room temperature. Homogeneity was secured by stirring the blend and analysing it for possible density gradients. The testing begun when such gradients had been alleviated

The equipment used for measuring the regulated emissions (CO, HC, NO_X and particulate) did conform to the specifications for measurement system given in Appendix 4 of ECE Regulation No. 49/02.

A hydraulic dynamometer by Zöllner and a "PUMA Test Assistant" control system by AVL were used for running and controlling the test engine. Regulated gaseous emissions were measured using an analysis system designed by BOO Instrument AB. The particulate matter was collected using AVL Mini Dilution Tunnel 474. Particulate filters used were of the make Pallflex TXH120WW, 70 mm.

Table 4: General features of the test engine.

Make, model	**VOLVO DH10A-285**
Number of cylinders and lay out	6, in-line
Displacement	9,6 dm^3
Injection pump	Electrically controlled mechanical in-line pump
Maximum power output	210 kW at 2000 rpm
Maximum torque	1200 Nm at 1450 rpm
Compression ratio	20:1
Start of injection at idle/factory setting	1,9 °CA BTDC
Combustion system	Direct injection, turbo-charged, inter-cooled
Emission level	Euro II

The test procedure used was the 13-mode test according to the ECE Regulation No. 49/02. The maximum power output as obtained with EC1 fuel was used also for RME fuel, while the maximum power output with Esterol-20 fuel was significantly lower than that for EC1.

The testing was conducted at normal, ambient temperatures. The engine was optimised for EC1 fuel for the tests of the EP I project. With the engine as of Table 4, fuel injection then started about 2 - 5 °CA ATDC (at intermediate and rated speed), what, considering the late ignition properties of RME fuel, might not have been favourable for Esterol-20 fuel featuring a lower Cetane value. *Therefore, additional testing (for the EP II project) was carried out with compensation (about 1,7 degrees) for the late ignition of Esterol-20 fuel.* In this way the Esterol fuel was given adequate burnout time, which should result in lower CO and HC values. The NO_X emission result could, however, become lower or higher than that of neat EC1 dependent upon whether the peak combustion temperature of the Esterol-20 fuel becomes lower or higher than that for EC1.

7.1.1 Results and remarks.

The numerical results of the tests are presented in Appendix 5 of ref. 1 (including the results in each one of the individual test modes of the ECE R49 test). The maximum power obtained with EC1 fuel was 190 kW at 2000 rpm and the maximum torque was 1100 Nm at 1450 rpm. The power loss obtained with the Esterol-20 fuel was about 20% relative to EC1 (cf. Appendix 5, ref. 1). Due to the late ignition timing with Esterol-20 in combination with the lower ignition propensity (the cetane value for the Esterol-20 fuel as measured in the VTT CFR engine was found to be unexpectedly low, namely 43 while the previously obtained value at the SGS laboratory in Gothenburg was about 47, cf. comment here below) of Esterol-20, the test engine did not run well on Esterol-20 fuel at low load conditions. The performance of the engine was rather unstable. A remedy for this behaviour would be to start injecting the fuel about 2 degrees earlier relative to the setting for EC1 in order to utilise the high compression ratio of the test engine (20:1, Table 4). Testing the engine in accordance with this recipe was also finally undertaken, what resulted, as expected, in a more stable performance. The exhaust gas emission levels for the three different fuel formulations (EC1, neat RME and Esterol-20) are depicted in Table 5. The accuracy of the measurements is (plus, minus) 5%.

The engine load settings were, however, considerably much lower during the testing for the Esterol-20 fuel as compared with EC1. Therefore, the exhaust gas emission values as obtained cannot be directly compared for the different fuel formulations. The overall trend seems, however, to be that the exhaust gas emission levels as obtained for the test engine while running on Esterol-20, are significantly higher than for MC1 with the exception of Bosch smoke values. One of the explanations for this result is that the test engine injection setting had been chosen so as to deliver minimum exhaust gas emission levels for EC1 fuel, what conceivably might have been tantamount to a disfavour for other fuel formulations, especially for Esterol-20 with its ignition delay and lower cetane value. This explanation seems to be justified considering the observation that the test engine did not run properly during the testing but, also, considering the higher CO- and HC-values for Esterol-20 of Table 5 below. Furthermore, the fuel consumption increased more for Esterol-20 than what could be accounted for considering the difference in heat content as compared with EC1. The adoption of an optimised ignition setting when using Esterol-20 would then, conceivably, improve the situation for Esterol-20 towards exhaust emission levels, which are in accordance with expectations (especially for the CO and HC emissions) and with previous international measurements (cf. ref. 6).

Accordingly, it was decided to carry out a test with advanced setting of the point of injection by -1,7 degrees CA. (EP II work). The results obtained confirmed, in general, the expectations regarding lower CO and HC emissions. However, the NO_X emission level seems to have increased somewhat as compared with the emission level as obtained for Esterol-20 with the standard injection setting (as for EC1 and RME). The imprecision of the measurements (± 5%, 2 sigma) is, however, large enough to render any firm conclusions uncertain. What seems certain, however, is that the NO_X emission level becomes significantly lower for Esterol-20 fuel than for neat RME with the same ignition setting. Another advantage achieved when advancing the start of ignition was an increase in the performance of the engine.

It has been pointed out here above, that a major cause of the poor engine performance of the test engine when driving on Esterol-20 fuel could be the impaired ignition quality of the fuel. Therefore, the cetane ratings both of the RME as used in blending the Esterol-20 fuel, and of the ready-made Esterol-20 fuel as well was checked out (by using the CFR engine of VTT). The base RME product as delivered by Svenska Ecobränsle AB and used in testing was then revealed to feature a cetane value as low as about 49. Furthermore, the cetanes rating for the ready-made Esterol-20 fuel was found to feature a cetane value as low as 39. This result was in contradiction with previous measurements carried through in EPI work (ref. 1), for which the cetane value of the neat RME (as supplied by Ecobränsle AB) was found to be 53 and that for Esterol-20 to be about 47. The conclusion is that the RME product quality may vary considerably to the disadvantage of the biodiesel concept in general. This feature may also be reflected in the various CFPP values as measured for Esterol-20 (ref.1). *It may therefore be appropriate to recommend that CFR measurements of the cetane rating should always be a part of the quality control procedures for fuels as based on RME.*

It seems inevitable, accordingly, to suggest the use of ignition improvers when running, especially, on low cetane RME, in a blend fuel formulation with ethanol while keeping the injection setting as for EC1 fuel in an Euro II, heavy duty diesel engine. While so doing it would seem possible to keep satisfactory performance of the engine and, at the same time, to achieve low emission levels of CO, HC, NO_X and particles.

A suitable ignition improver additive would be the compound EthylHexylNitrate ("EHN"), which is in general use commercially for increasing the ignition quality of commercial diesel fuels of fossil origin. The needed concentration of EHN in order to achieve satisfactory combustion performance of Esterol-20 should then be determined prior to field testing. Judging from levels applied for fossil diesel oils it can be estimated that a level of some few thousand of ppms would be satisfactory, what would increase the fuel price only marginally.

One of the major reasons for selecting Esterol-20 as the fuel of preference for ordinary CI engines in the project was that it would be desirable to avoid fuel price increases by designing a fuel formulation which did not include high cost components. However, if ignition improvers are to be used in Esterol fuel blends (due to technical constraints and circumstances) the ethanol content could be increased still further in order to achieve still better and lower exhaust emission levels for ordinary, non-dedicated diesel engines. It could, for instance, then be appropriate to increase the ethanol content up to about 30% ("Esterol-30") in the Esterol fuel, thus achieving more significant exhaust emission improvements even for NO_X as compared to EC1. The necessary increase of ignition improver additive to achieve adequate engine performance would then probably not add to the fuel price significantly.

In this context it is appropriate to mention, however, that the Swedish diesel fuel quality EC1 (here used as reference fuel) is, environmentally speaking, most probably superior to any other fossil diesel fuel qualities as presently being marketed in Europe. Accordingly, EC1 becomes "hard to beat" for, especially, vegetable oil fuels on condition that it is being used in the most modern diesel engine designs. Saying this may be tantamount to suggesting that comparisons made between the use of (RME and) Esterol-20 and fossil diesel fuels of conventional European specs, would, probably, more clearly reveal the capacity to emulate the environmental performance of conventional, fossil-based diesel fuels. It should also be mentioned, that the test results as obtained can be expected to have become more favourable for Esterol-20 fuel had the base RME oil as supplied by Svenska Ecobränsle AB been of a higher cetane rating. This company has previously delivered RME to the project, which featured a cetane NR of 53 providing an Esterol-20 cetane NR of about 47, what has been proved to be adequate for achieving trouble-free performance of diesel engines of normal CR ratios (cf. the field testing as reported here below).

As is clear from Table 5 here below, Esterol-20 meets all the regulated requirements for Euro II engines and is superior in regard of Bosch smoke emissions. The particle emission seems, however, to increase when using the same injection setting for Esterol-20 as for EC1. The PM emission level seems, also, to decrease considerably following advancement of the fuel injection by 1,7 degrees, what is in accordance with expectations. It has also been demonstrated during project implementation, that a method for decreasing (or, rather, almost alleviating) the PM emissions from Esterol-20 driving could be to equip the engine with an oxidative, two-way catalyst.

Table 5: Results of the exhaust gas emission testing according to the ECE R49 test procedure with the VOLVO DH10A-285 engine (dynamometer settings are given in Appendix 5, ref.1). Accuracy of measurements: +-5%.

Fuel	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	Particles (g/kWh)	CO_2 (g/kWh)	Fuel cons. (g/kWh)	Bosch smoke*)
(Euro II Requirement)	4,0	1,1	7,0	0,15			
EC1	0,56	0,18	5,5	0,095	682	229	0,44
Esterol-20	1,22	0,26	6,2	0,135	712	287	0,05
Esterol-20	1,12	0,23	5,9	0,094	719	289	0,05
Esterol-20 -1,7 °CA	0,80	0,18	6,6	0,077	706	283	0,05
RME	0,52	0,07	7,2	0,066	688	260	0,12

*) Average value without weighting factors

8. Conclusions.

The results presented here above have revealed and made it clear, that the fuel formulations of Esterol A and –B should be completely satisfactory as fuels for certain CI engines, which have been dedicated to neat ethanol fuel use. This means that RME can be used as an ignition improver additive for neat ethanol fuel for (e g) the Swedish ethanol bus fleet using Scania dedicated ethanol engines.

The new neat ethanol fuel formulations are just as environmentally benign as the present ethanol fuel formula so far used featuring Beraid as ignition improver. Esterol A with a minimum amount of RME in azeotropic fuel ethanol will, therefore, be preferred as the optimum fuel for the present and pending field tests with some small number of city buses in, possibly, also Stockholm in addition to the tests having been reported here above. The ethanol bus supplier, Scania CV AB, has been completely informed about the test results so far obtained during project implementation.

Further, the greenhouse gas effect due to the combustion of the Esterol fuel blend, has potential of becoming minimal, thereby contributing to meet set European goals for the greenhouse gas effect if the use of Esterol fuels were developed and used.

The development and testing of RME (or FAME) as an ignition improver for neat alcohol fuels will also feature further advantages. Accordingly, in contrast to the well-known case of 'Avocet' (which disappeared suddenly from the market leaving the neat ethanol fuel test fleets in Europe without any other alternative than to close test operations), RME (or, more generally, FAME) will always be available as long as European agriculture will continue to grow rape oil plants. The supply of ignition improvers for neat alcohol diesel fuel formulations will therefore become far less vulnerable and more sustainable with RME than with other alternatives, which would depend too much on, possibly negative, business strategic decisions by the established chemical industry.

The project will be followed by extended field tests of 5 city buses in Stockholm in order to further confirm the positive results so far obtained and to expand the knowledge and information on the cold temperature properties of Esterol fuel formulations of neat ethanol diesel fuels. The Stockholm field tests are planned to be carried through during the winter 2000/2001 up to May 2001, when the results will be assessed and evaluated. Hopefully, it will be possible to substitute fossil based Beraid as ignition enhancing agent with renewable RME for the ethanol buses in Sweden and elsewhere in Europe.

8.1 Prospective economic and environmental advantages of Esterol fuel formulations of neat ethanol for CI engines.

The use of the Esterol fuel formulations (as developed and tested in the present project) for dedicated neat ethanol engines featuring high compression will make it possible also to lower the price per litre of the ethanol fuels. Because the fuel consumption can be lowered with about 5%, due to the higher heat content of Esterol fuel formulations, the mileage cost for fuel can be decreased even further. The cost savings due to these differences may be estimated to reach a level of some 10% lowering of the total price for the ethanol fuel. It is also conceivable that the cost for maintenance of vehicles on Esterol fuel formulations could become significantly cheaper partly due to the excellent lubrication properties of the RME component, accordingly minimising fuel pump problems which otherwise could add much to the maintenance costs for neat ethanol vehicles.

Furthermore, the use of RME as ignition enhancer for bioalcohol fuels would also improve the prospects of more successful abatement of the increasing seriousness of the greenhouse gas emissions from traffic. While the presently used ignition improver substance – Beraid – is based on fossil raw materials, will an Esterol fuel formulation feature the merit of being produced entirely from renewable raw materials. This feature would also increase the robustness and sustainability of the ethanol fuel option for vehicles as powered by CI engines.

9. Project reporting and conference presentations.

Project progress has been reported as follows:

1) Interim report, disseminated in October 1999

2) Addendum to the interim report, disseminated in December 1999

3) 2nd addendum to the interim report, disseminated in March 2000

4) Final report (this report), November 2000-11-01

5) Paper on the project presented at ISAF XIII, the International Symposium on Alcohol Fuels, held in Stockholm July 3rd to July 5th 2000. (Paper No 6 in the Conference proceedings, vol. II, included in this report as Annex 6).

6) Visual presentation at the Altener 2000, Conference and Exhibition, "Renewable Energy for Europe" in Toulouse, France, on 23-25 October 2000 (Project poster in the Swedish stand No 21 at the exhibition).

Acknowledgement.

The financial support from the EU ALTENER program, from the Swedish National Energy Administration and from the Swedish Transport and Communications Research Board is gratefully acknowledged.

References

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"Use of biofuel blend with esterified vegetable oil and bioethanol as a more environmentally benign motor fuel."
Altener contract No XVII/4.1030/Z/96-078.

2. Egon A Larsson, ELAB Engineering & Development Co:
"Etanoldrivna stadsbussar i Örnsköldsvik"
Report in Swedish. English title:
"City buses on ethanol in the city of Örnsköldsvik"
(Abstract in english)
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3. Charlie Rydén, AB Storstockholms lokaltrafik, and Karl-Erik Egebäck:
"Flottförsök med 32 etanolbussar vid AB Storstockholms Lokaltrafik"
Report in Swedish. English translation of title:
"Fleet test with 32 ethanol propelled buses in innercity service in Stockholm"
KFB-report 1994:2; NUTEK report R 1995:6.

4. Karl-Erik Egebäck, Roger Westerholm, Peter Ahlvik, Anders Laveskog:
"BIODRIVMEDEL. Utvärdering och förslag till motorteknisk utveckling."
Report in Swedish. English translation of title:
"BIOFUELS. Evaluation of exhaust gas emission testing including proposals for engine development program."
KFB-report 1998:2

5. Egon A Larsson, ELAB Engineering & Development Co:
"Esterol, a biofuel blend with esterified vegetable oil and bioethanol, as a more environmentally benign motor fuel."
ISAF XIII, International Symposium on Alcohol Fuels, Stockholm 3-6 July 2000, Conference proceedings, Vol. II, paper No 6.

6. See for instance proceedings from "Fachtagung BIODIESEL, Optimierungspotentiale und Umwelteffekte, Informationen, Erfahrungsaustausch, Perspektiven", June 12-13th 1998, Forum der FAL, Braunschweig, Bundesforschungsanstalt für Landwirtschaft, Fachhochschule Coburg, Germany.

ESTEROL II

Annex 1

Cold start tests on Esterol fuel formulations for dedicated ethanol CI engines

Projekt: Etanol-rme

Kallstart:

- 2 minuter- tomgång
- 5 minuter - varvtal 1100 rpm och belastning 550 Nm.

Opacitetsmätningar på kallstarter har mätts med 3 sek. mätintervall.

Både opacitet och temperatur har mätts på kallstarter vid 16%(16rmek2), 18%(18rmek2), 20% (20rmek8), 25%(25rmek2) och etanolen från LLT*/(erberk) med kort sugslang för att undvika kondensproblem.

*/ LLT – Etanolbränsle med bereid som används av Luleå lokaltrafik i sina etanolbussar.

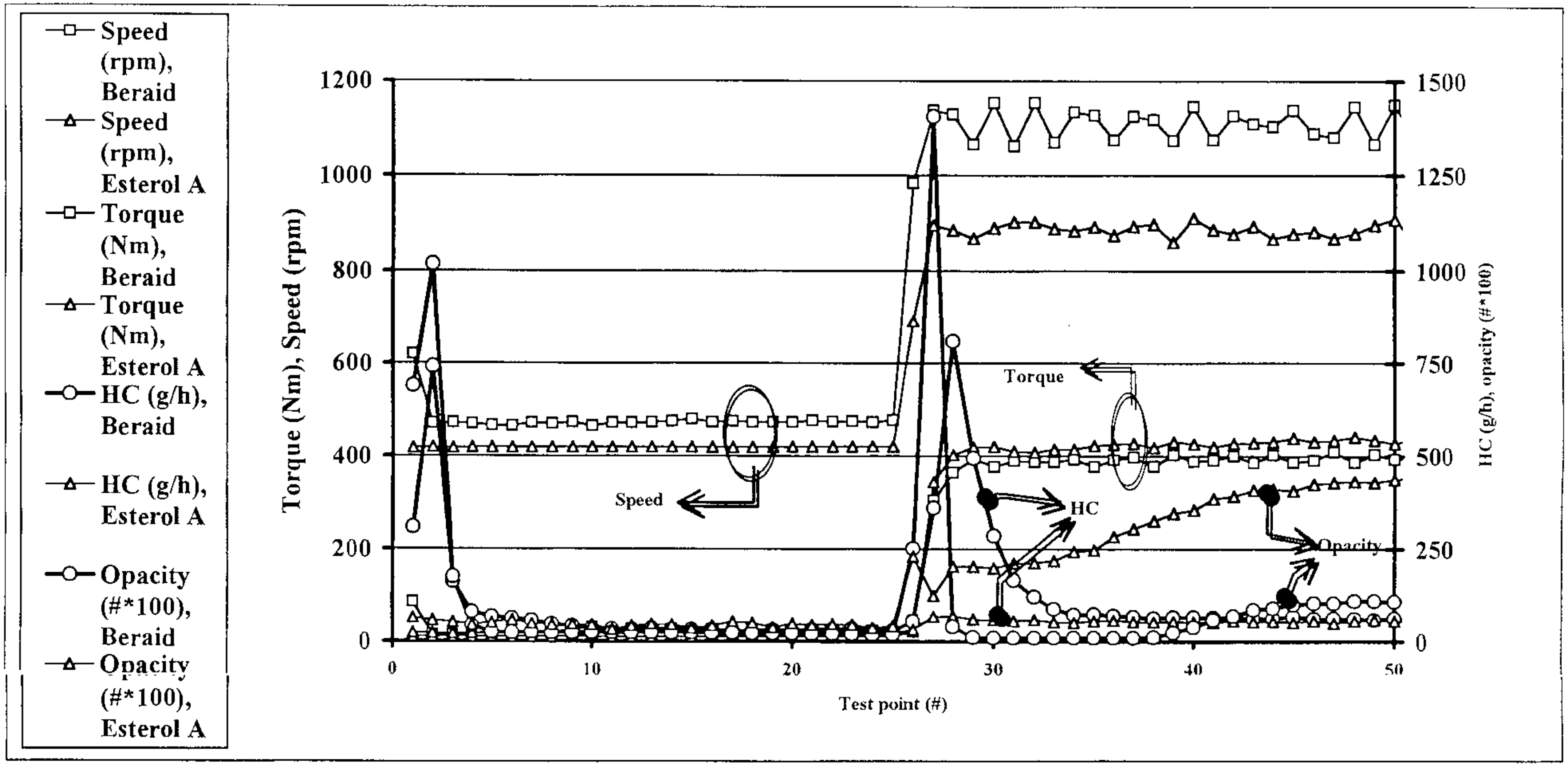
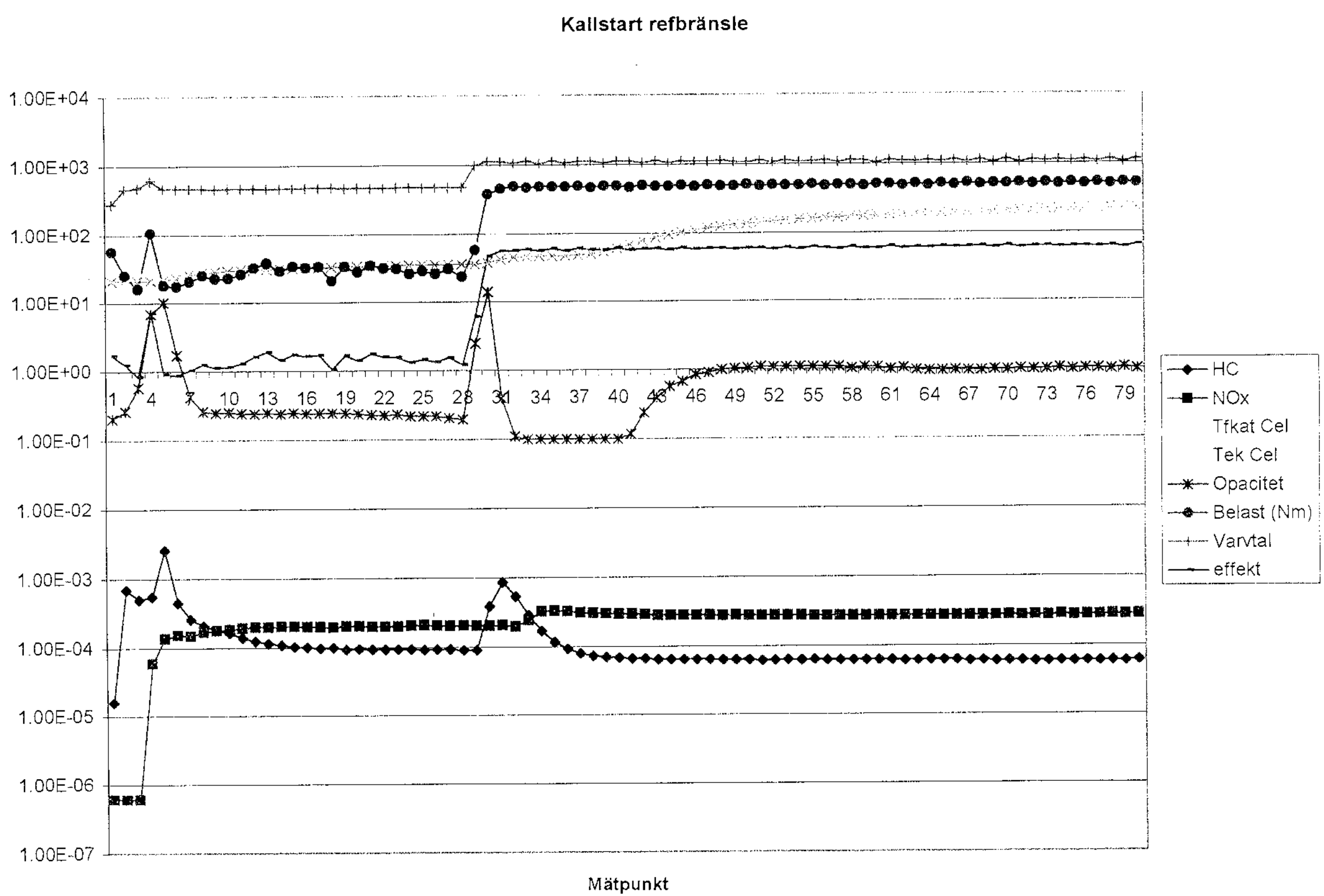
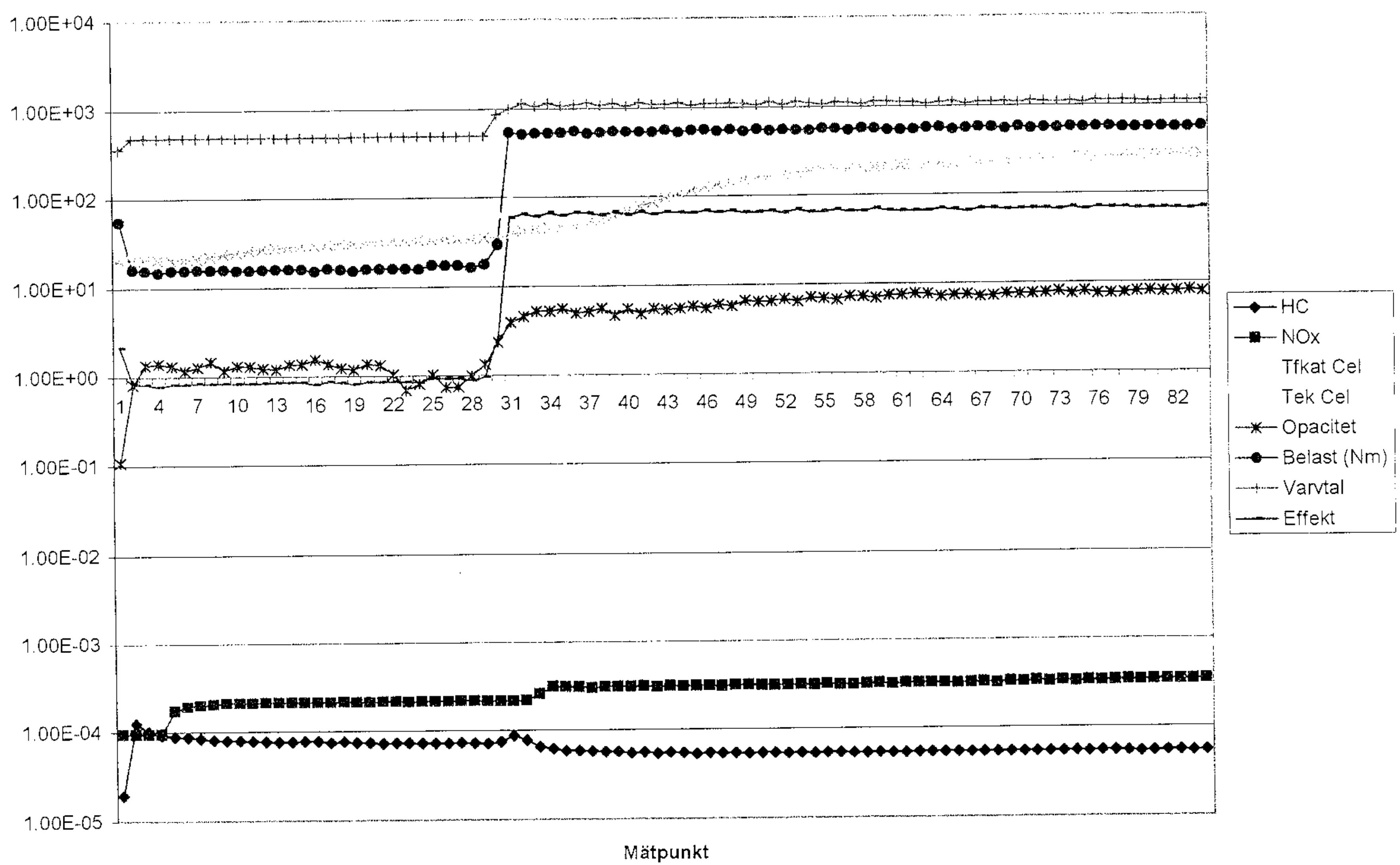


Diagram 3: Cold start properties of Esterol vs Beraid ethanol fuel formulas

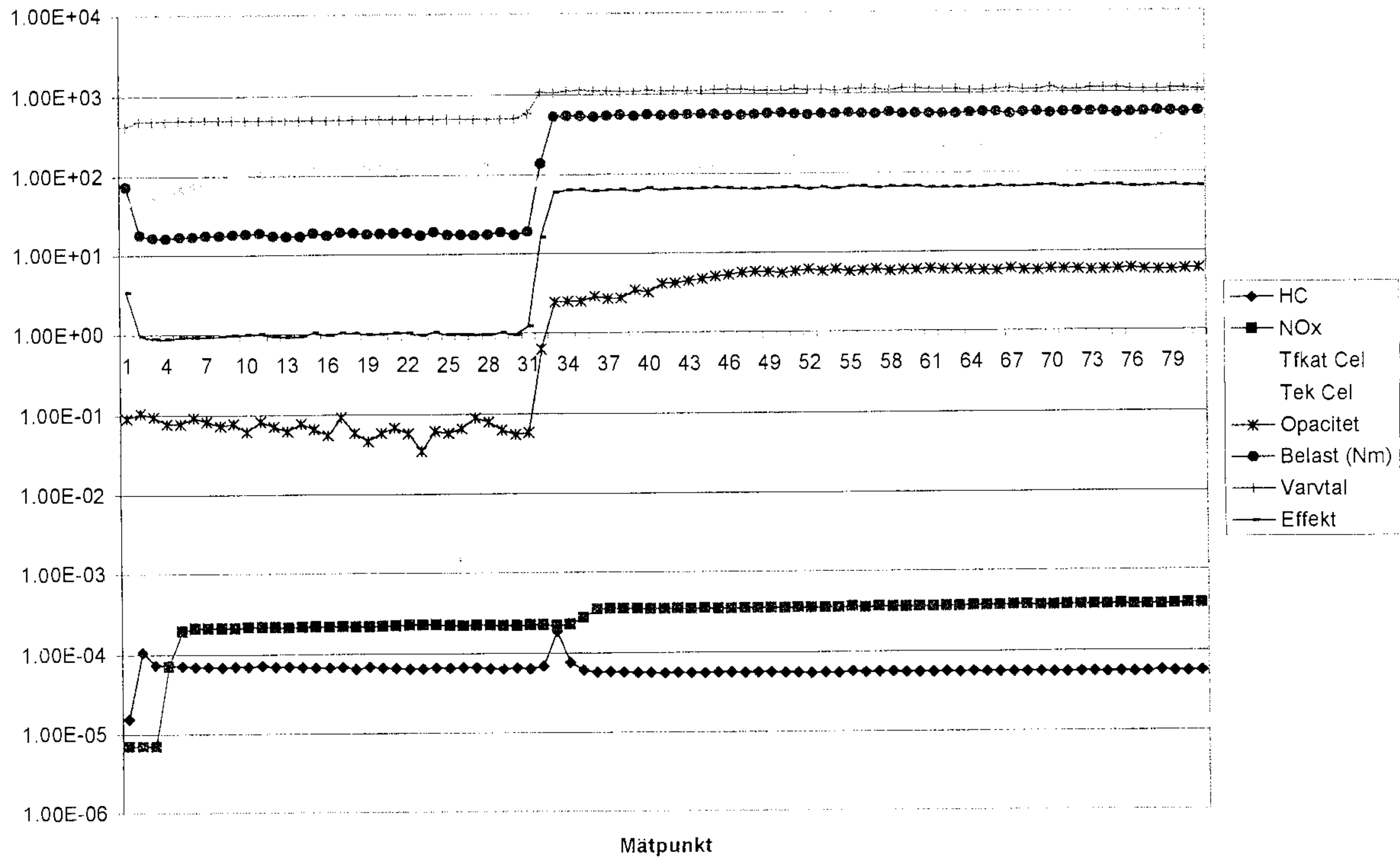


Kallstart refbränsle
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79
Mätpunkt
HC
NOx
Tfkat Cel
Tek Cel
Opacitet
Belast (Nm)
Varvtal
effekt

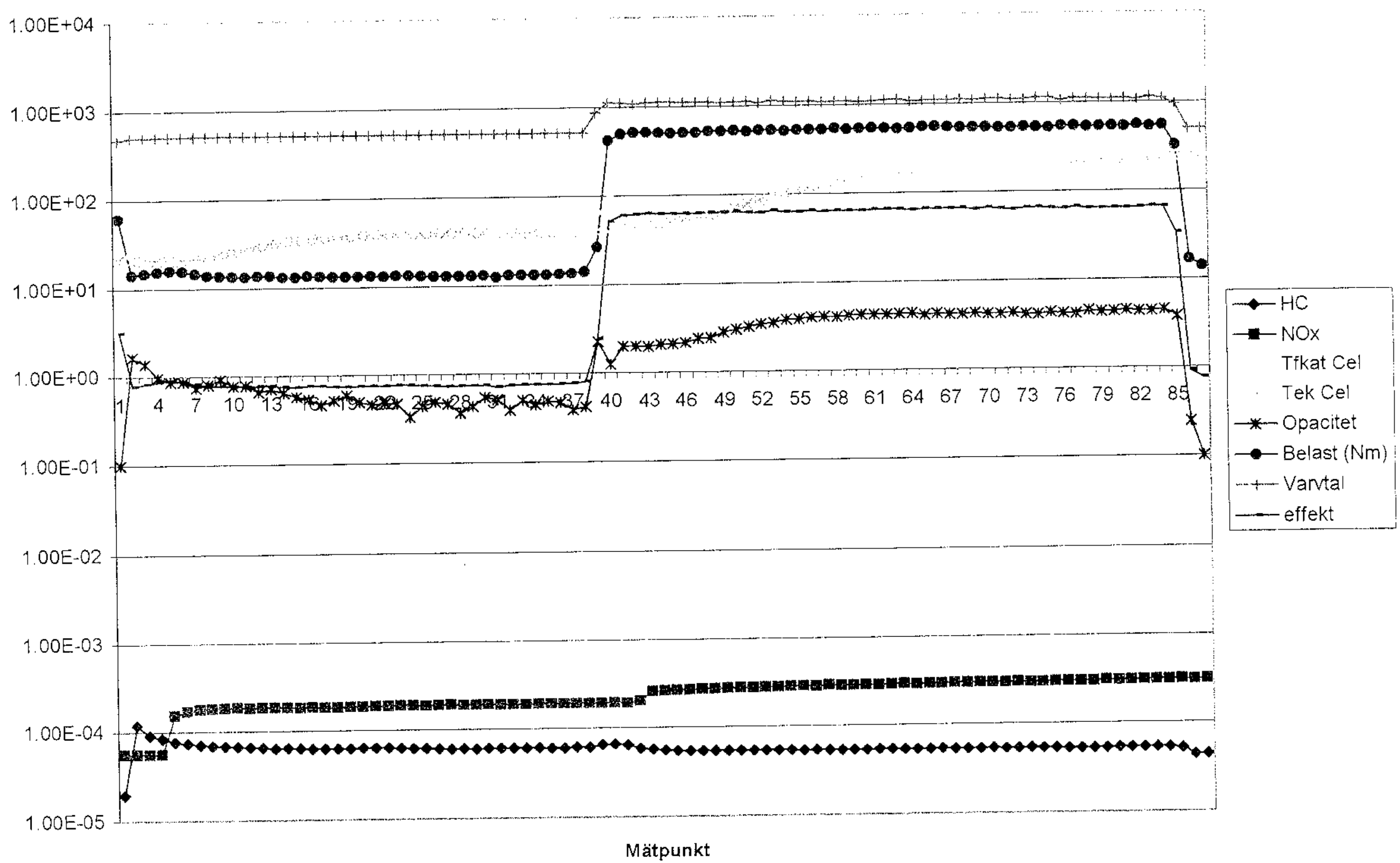
Kallstart för 25RME



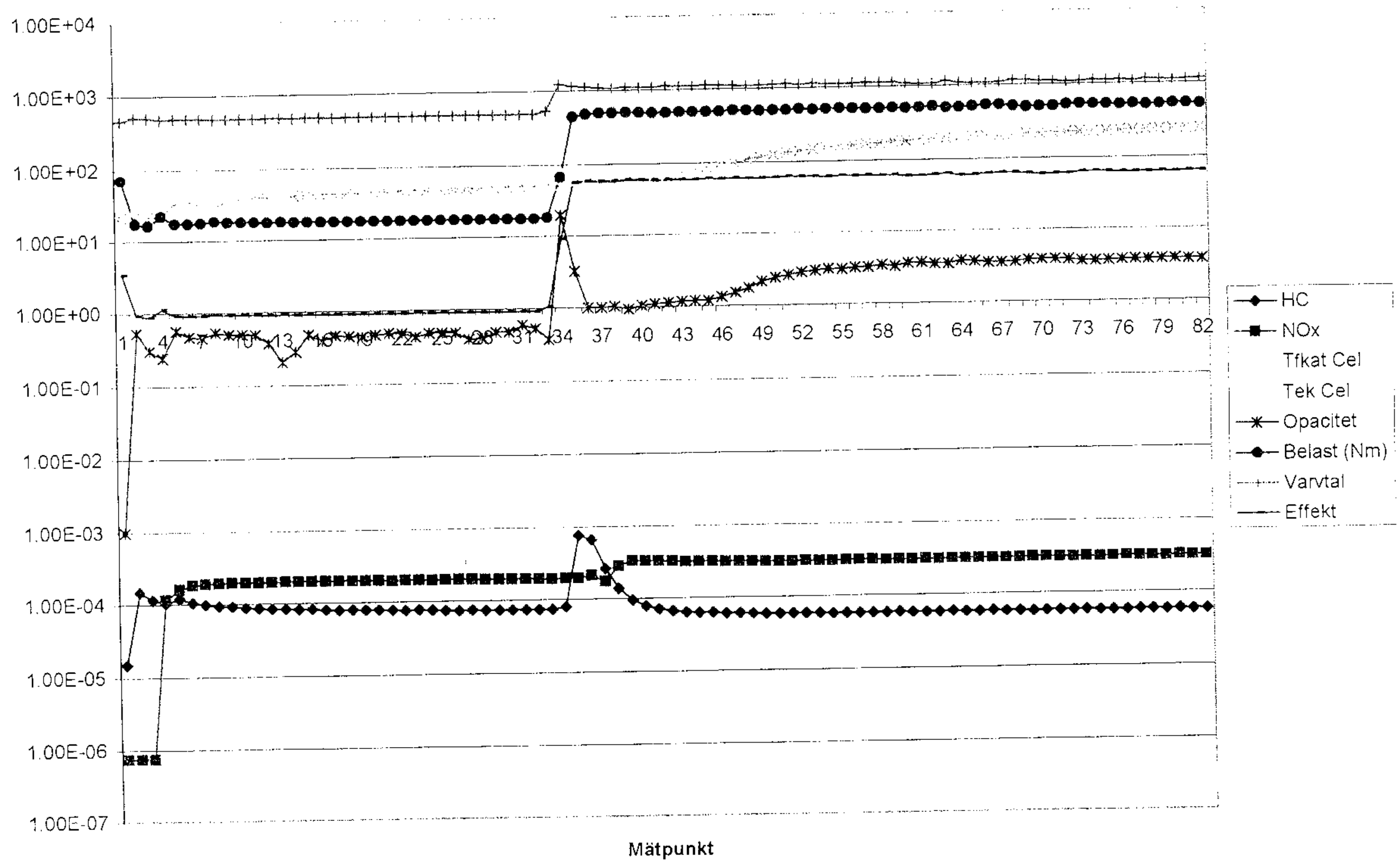
Kallstart 20RME



Kallstart 18RME



Kallstart 16 RME



Annex 2

Catalytic exhaust gas converter, suitable for RME.

Oberland Mangold GmbH

Katalysatortechnik

ELAB Eng.&Development Co.
Mr. Egon Larsson
Pilos Väg 4

S - 611 36 NYKÖPING

Dipl.-Ing. (FH) B. Kahlert
Product Manager
Diesel Systems
Tel.: ++49-8821-9338-24
Fax: ++49-8821-9338-33

November 27th 1998

Dear Mr. Larson,

please excuse the belated reply for which I am very sorry, but at present I am obliged to treat a great multitude of customers documentation. Regarding your inquiry about the RME-Oxydation-Catalyst (Biodiesel-Catalyst) we like to give you the follwing offer:

1. Scania truck, type P 92 M 4 x 2:
   Diesel engine: Scania DSC 9; turbo-charged engine, piston displacement 8,500 cm³, nominal speed: 2,000 rpm, exhaust gas flow: approx. 930 Nm³ /h.

   RME-Oxydation-Catalyst:
   Number: 1 piece
   Price: 3.900,- DM (german marks)

2. Scania truck, type P 112 M 4 x 2:
   Diesel engine: Scania DS 11, turbo-charged engine, piston displacement 11,000 cm³, nominal speed: 2.000 rpm., exhaust gas flow: approx. 1,100 Nm³/h

   RME-Oxydation-Catalyst:
   Number: 1 piece
   Price: 4.600,- DM (german marks)

The offered price comprises the Catalytic Converter as well as the integration of the Catalytic Converter in an original exhaust gas silencer. But the silencer for the catalytic converter integration has not been included in the offered price above.

So far you have not yet been able to communicate to us informative data on the exhaust gas silencers for the Scania trucks. Therefore, our above offer will only be valid on the prerequisite condition that the offered Catalytic Converters will fit into the silencer.

Oberland Mangold is a well known manufacturer of catalysts like three-way-catalysts as well as oxidation catalysts and particle-filter-systems (soot traps) for passenger cars, trucks, utility vehicles, two-wheelers, construction machinery, stationary engines and busses.

Regarding the RME-Oxydation-Catalyst retrofitment, Oberland Mangold is also a well reputated expert in the field of catalytic converter replacement for trucks. We have also made the RME-Oxydation-Catalyst retrofitment for many trucks here in Germany.

Oberland MANGOLD GMBH

Katalysatortechnik

Documentation/technical information

A documentation on our RME-Oxydation-Catalyst in english language is not yet available, which we regret very much. But we add and append to this letter an English language brochure of the German Technical Surveillance Agency „TÜV“ (*), which deals with our RME-Oxydation-Catalyst.

(*) Since the German abbreviation „TÜV“ - a German Technical Surveillance Agency, installed by the Government (but a private company) - is not known everywhere abroad, this agency has the inspecting tasks of technical matters and technical releases.

Fitment of the RME-Oxydation-Catalyst

For trucks the catalyst will be combined with the silencer, that means the converter will be integrated into the silencer. For this reason, the outer dimensions of a serial silencer will not be changed. The silencer with an integrated catalyst can also be fitted into the truck like a serial silencer. Therefore, no changes on the vehicle are necessary and there is no negative effect on the vehicles operating performance.

Life duration of the catalytic converter

As we are using for our RME-Oxydation-Catalyst only metal substrates (metal monolites) from high temperature resistant stainless steel (V2A), the life duration of the catalytic converter corresponds to the life duration of the Diesel engine. Metal substrates are mechanically and thermal high resistant and cannot be destroyed by vibrations and thermal shocks as ceramic catalysts can be done.

Maintenance / bad fuel quality

Our catalysts are free of maintenance and until a drive duration of 250.000 kms they show no worth mentioning reduction of their effectiveness. If - owing to bad fuel quality - high deposits in reductions of effectiveness arise on the catalytic converter surface, they can be removed by blowing through the catalyst with compressed air or by addition of a special fuel additive, which we also can supply.

Details of performance of the catalytic converter

With an Oberland RME-Oxidation-Catalyst (Biodiesel-Catalyst) the following conversion rates of pollutants can be reached:

Conversion of CO emissions:	99 percent
Conversion of HC emissions:	95 percent
Conversion of PAH emissions:	75 percent
Conversion of particle emissions:	50 percent
Conversion of NOx emissions:	20 percent
Conversion of unlimited pollutants :	70 - 90 percent

The disagreeable exhaust gas smell (caused by a substance called acroleine), which appears when operating a vehicle with biodiesel, will be completely eliminated by our RME-Oxydation-Catalyst.

Oberland-Mangold GmbH · Amselstr. 4 · 82467 Garmisch-Partenkirchen · Tel. 0 88 21/93 38-0 · Fax 0 88 21/94 77 38
Internet: http://www.oberland-mangold.de eMail: oberland_mangold@compuserve.com
Registergericht München HRB 76593 · Geschäftsführer: Anton Mangold

Oberland MANGOLD GMBH

Katalysatortechnik

Light-off temperature

Our RME-Oxydation-Catalyst dispose of a light-off temperature of approx. 170° C of exhaust gas temperature. Since we employ exclusively metal monoliths, thus, our Catalytic Converters are in a position to heat up within a very short time. Please learn the details from the attached information sheet on „metal substrates“.

Effects of the catalytic converter to the engine respective the vehicle:

By use of a metal substrate with a very low wall thickness of only 47 um the exhaust gas back pressure will be increased only minimal. For this reason, the exhaust gas back pressure with metal catalytic converters is 60 percent lower compared to those of ceramic catalytic converters. Therefore, no negative influence on engine performance, fuel consumption and the operating behaviour of the engine could be stated by several investigations carried out by the german TÜV (german technical surveillance agency) and other independent instutes. The temperature of the exhaust gas after catalytic converter will be increased on 30 °C maximum. The catalytic converter has a high sound-absorbing effect so that noise emissions of the vehicle will clearly be reduced after fitment of a catalytic converter.

We hope, that the above-mentioned informations are helpful for you. We enclose the corresponding informations about our catalytic converters. Should you require further information, we will, of course, be at your kind disposal.

We would be pleased to cooperate with you and thank your for your interest in our company.

With kind regards,

OBERLAND MANGOLD GMBH

Dipl.-Ing. (FH) B. Kahlert
sales & marketing manager

Enclosure

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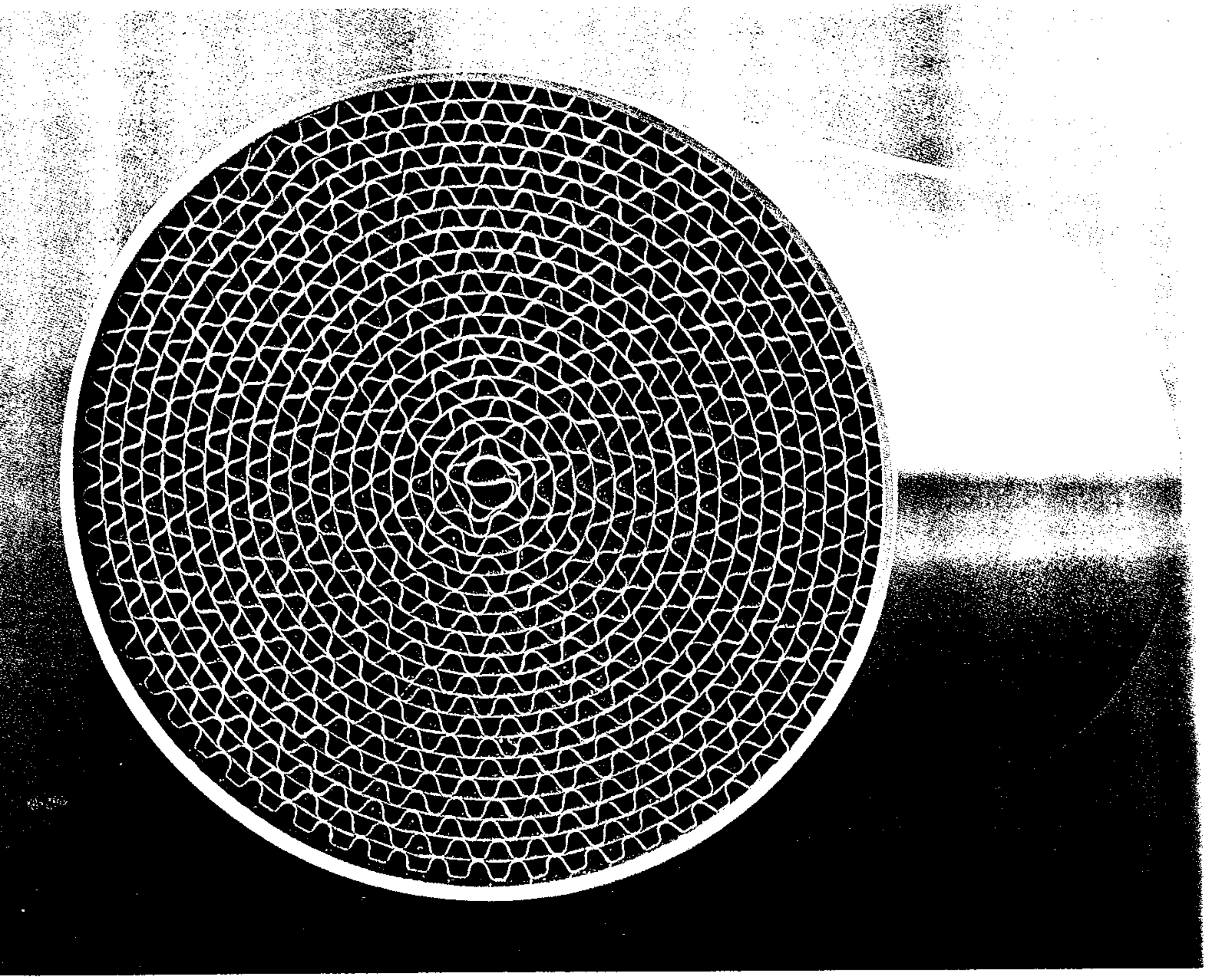
Internet: http://www.oberland-mangold.de eMail: oberland_mangold@compuserve.com
Registergericht München HRB 76593 · Geschäftsführer: Anton Mangold

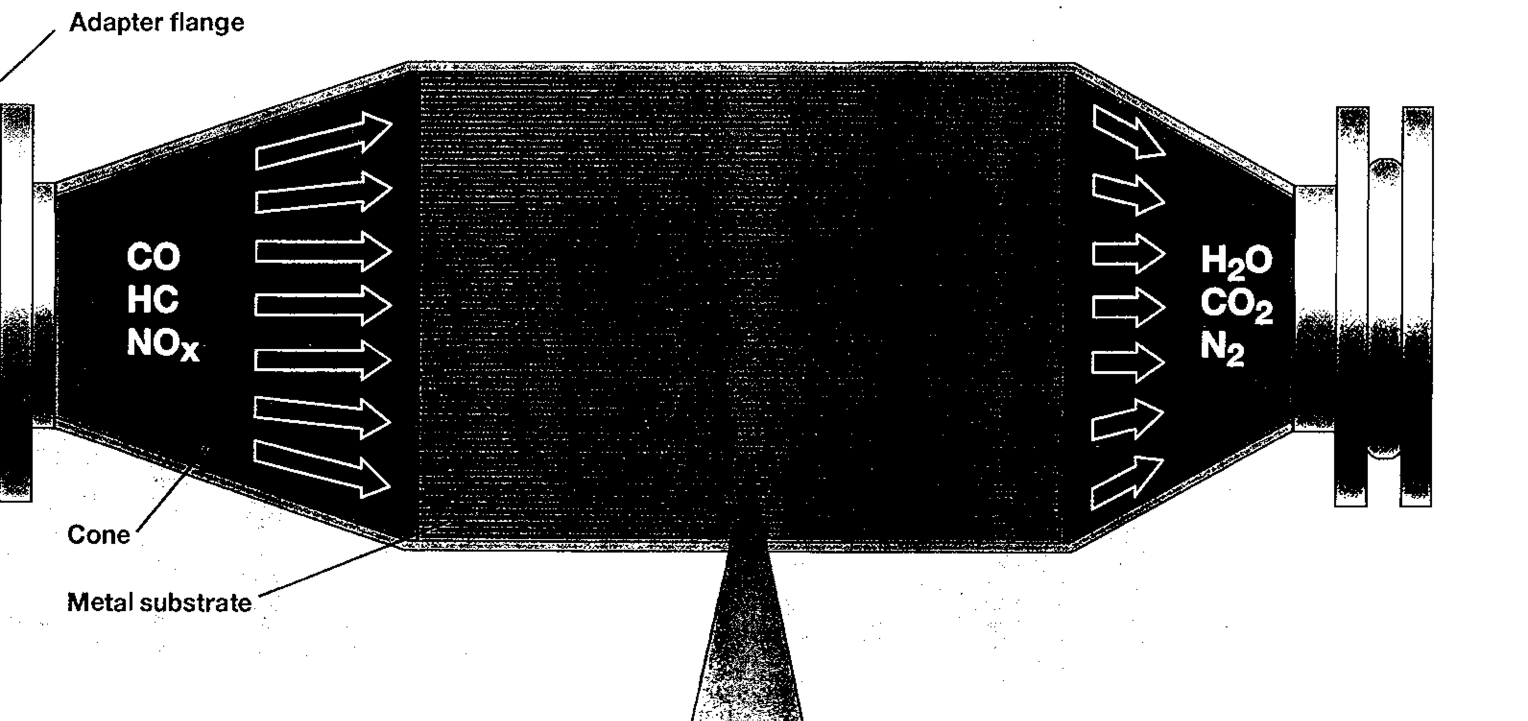
Oberland Mangold GmbH

Catalytic Converter Technology



Metal Substrates for Catalytic Converters

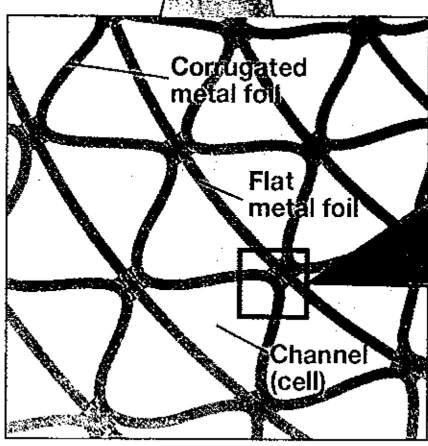
Design of metal-substrate catalytic converters



Three-way catalytic converter

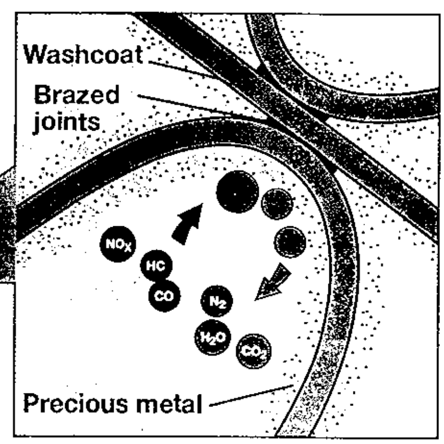
The **metal substrate** consists of a honeycomb matrix surrounded by a tubular mantle. This mantle can form the housing, with a reduction **cone** welded to each end. To incorporate the catalytic converter in the exhaust system, an **adapter flange** is welded to each cone. The exhaust gases permeate the channels (cells) of the matrix; the pollutants CO, HC, and NO_X are converted into the harmless compounds H_2O, CO_2, and N_2 on coming into contact with the catalytic-activ substrate.


TÜV CERT
ZERTIFIKAT
Die TÜV CERT-Zertifizierungsstelle der TÜV Management Service GmbH bescheinigt gemäß TÜV CERT-Verfahren, daß das Unternehmen
Oberland Mangold
Katalysatortechnik
für den Geltungsbereich
Metallkatalysatoren und Abgasreinigungssysteme
ein Qualitätsmanagementsystem eingeführt hat und anwendet.
Durch ein Audit, Bericht-Nr. 24022576 wurde der Nachweis erbracht, daß die Forderungen der
DIN EN ISO 9001 :1994
erfüllt sind.
Zertifikat-Registrier-Nr. 12 100 9719
TÜV
MANAGEMENT SERVICE



Matrix

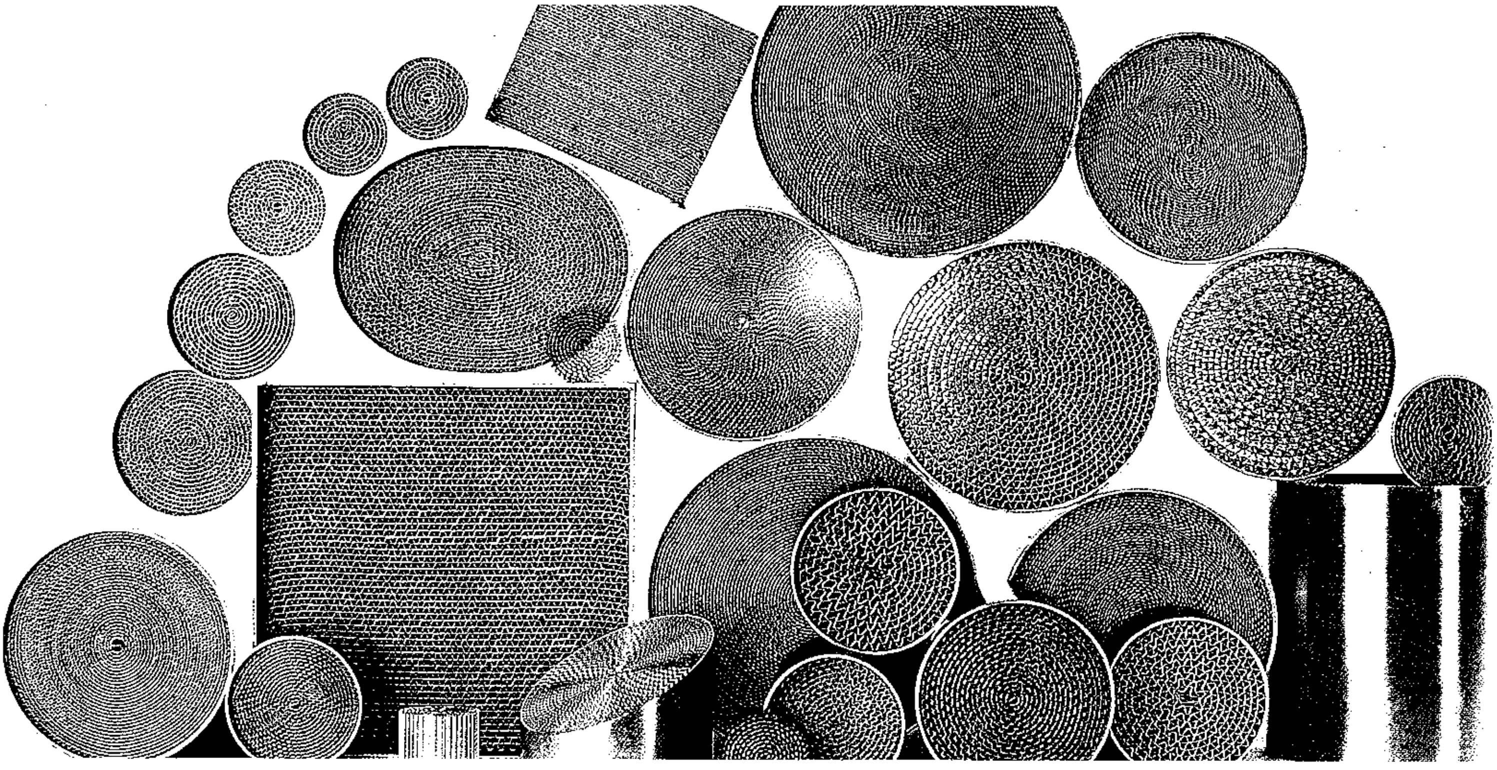
The metal substrate is manufactured by spirally winding a **flat** and a **corrugated** metal foil. The result is a cylinder containing longitudinal **channels.** The metal foils are made of corrosion-resistant ferritic steel (Al-Cr alloy) which withstands high temperatures. Vaccum brazing is used to attach the foils to each other and the wound matrix to the mantle tube. The size of the cells is determined by the geometry of the corrugated metal foil; the cell density is defined as the number of cells per square inch of cross-section.



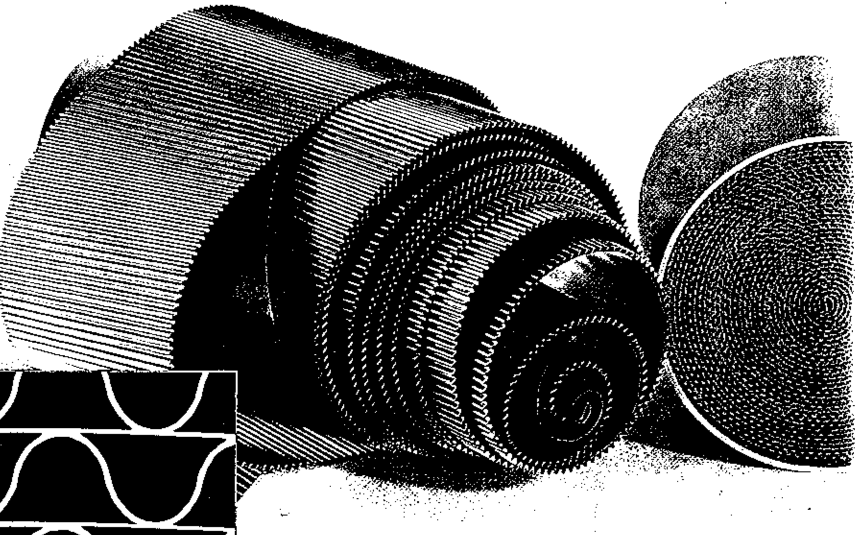
Metal foil

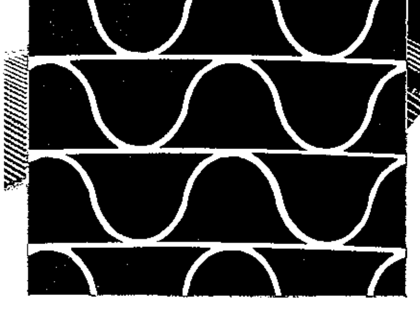
In order to increase the surface area of the metal foil, a porous intermediate coating **(washcoat)** is applied, to which the catalytically active particles of **precious metal** adhere. Precious-metal catalysts enable the exhaust pollutants to be converted; platinum, rhodium, and palladium are used in catalytic converters. Good adhesion of the washcoat on the substrate is essential if the catalysis is to proceed efficiently and reliably. Precise **brazed joints** ensure good mechanical stability and consequent long life of the catalytic converter.

Metal-substrate technology



Oberland Research & Development

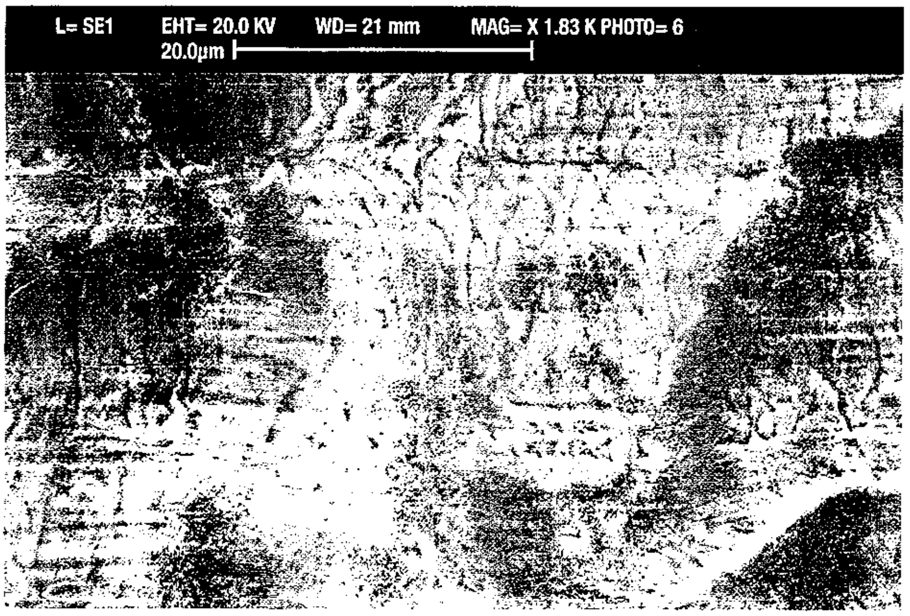




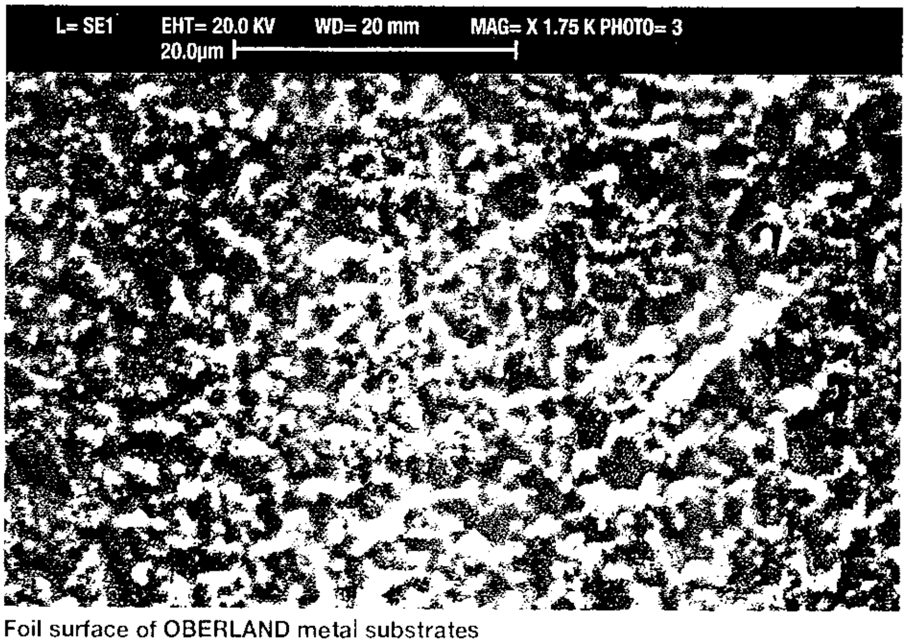
Following many years of R&D work, OBERLAND metal substrates have been in series production since 1992. Specially developed production techniques have significantly improved the service life compared to conventional spiral-wound metal substrates. The new manufacturing process has completely eliminated the telescope effect or a tendency for the matrix to become detached from the mantle. OBERLAND metal substrates meet all technical requirements (temperature stability, long-term mechanical strength, long service life). Strain tests, fatigue tests, and trials in practical use have proved the high quality of OBERLAND metal substrates.

The design of the brazing and thermal treatment processes, and the consistent quality of the metal foil and the brazing metal, have had a decisive influence on the long-term mechanical strength and thermal stability of the matrix. By varying the components of the alloy (Al, Cr, Ce, etc.), OBERLAND has achieved the best possible resistance to oxidation (high-temperature corrosion resistance) and yield strength of the metal foil. Our engineers were able to produce sturdy brazed joints at the points where the layers make contact, by optimizing the brazing alloy and precise regulation of the amount used. The low coefficient of expansion and high thermal conductivity of the foil result in very high stability under alternating stresses such as occur when the exhaust gas temperature varies. OBERLAND has thus created a matrix that withstands high temperatures and mechanical stress, and at the same time resists corrosion. The melting point of the matrix is approximately 1500°C. OBERLAND metal substrates can be subjected to operating temperatures of up to 1300°C for short periods without any detrimental effect.

Materials development



Untreated foil surface



Foil surface of OBERLAND metal substrates

Metal foil quality

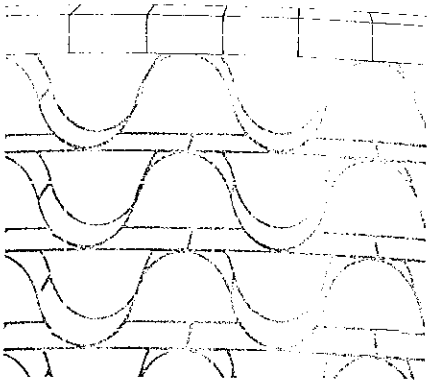
Perfect adhesion of the washcoat on the metal foil surface must be assured. Acting in close cooperation with the companies which apply the washcoat and the precious metals, OBERLAND therefore laid down the requirements placed on the coating technology. These have since formed the basis for many years of research and development; the result is a highly specialized foil material. Various matched production processes first produce a permanent layer of aluminium oxide on the surface of the foil.

This permits optimum adhesion of the washcoat, thus ensuring the long-term stability of the active catalyst coating. Thanks to its protective nature, it prevents the foil surface becoming brittle, while stabilizing the washcoat at the same time. The pictures above, taken with a scanning electron microscope, show the formation of the aluminium oxide layer during the heat treatment processes specific to OBERLAND.

OBERLAND uses modern production plant and processes for manufacturing metal substrates, both in large series and to customers' specifications.

We place great importance on the development of new foil and braze materials, with further improvements in the thermal and mechanical strength of the matrix, by optimizing the production processes.

New flexible manufacturing processes allow rational production of many different sizes of catalytic converter, thus ensuring quick reaction to varying market demands.

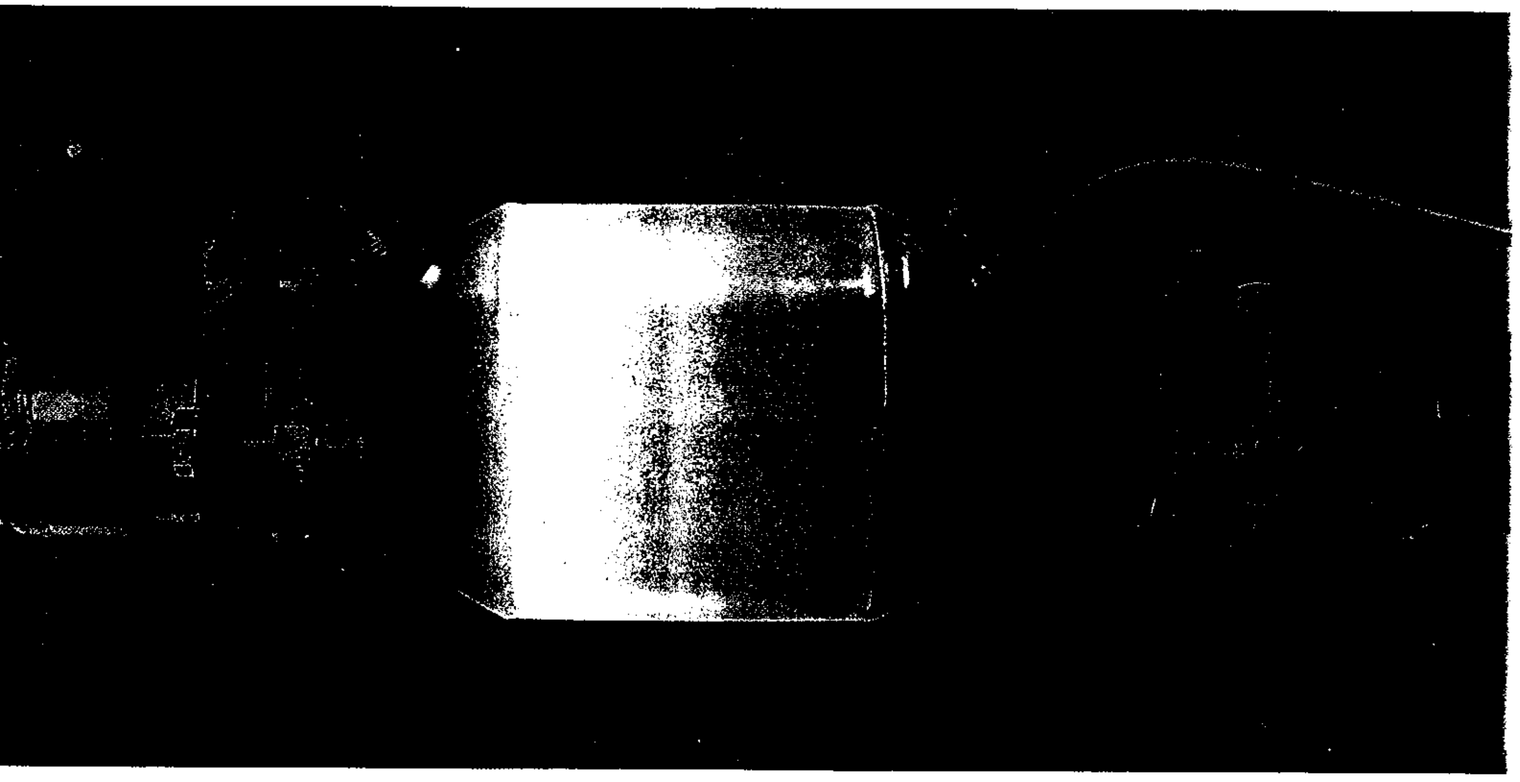


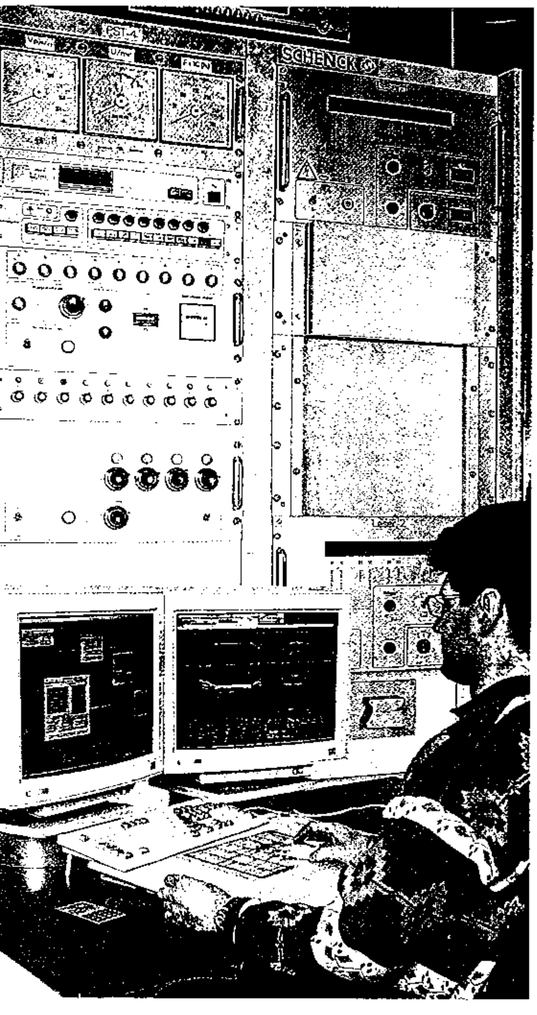
All foil and mantle materials are subjected to accelerated aging tests before being released for series production. This guarantees a consistently high quality of metal substrate.

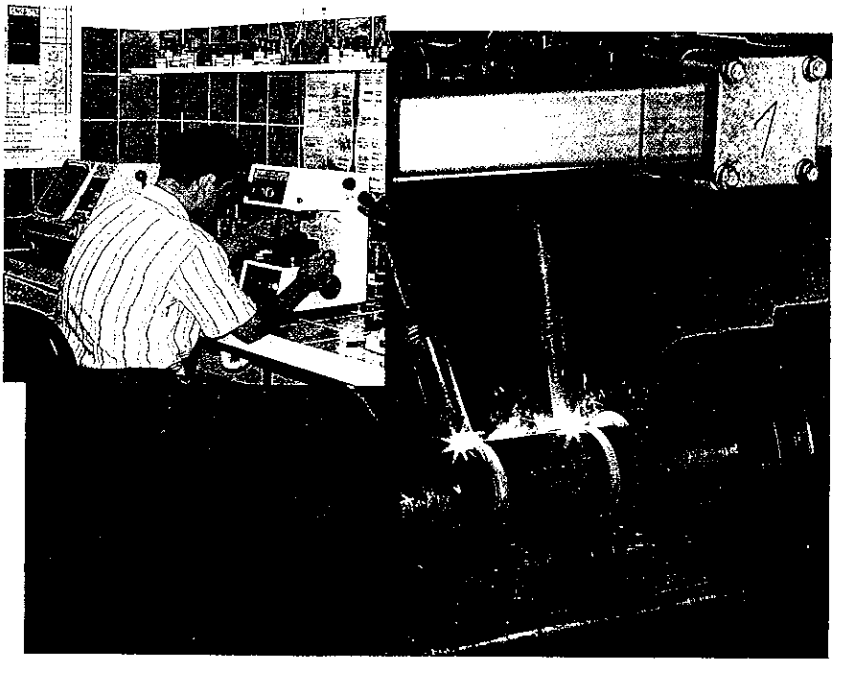
All production processes are fully automated and monitored, in order to maintain a constant high level of quality.

The process monitoring starts with the incoming materials, extending all the way to a 100% outgoing quality check. It makes full use of statistical methods.

Manufacture and quality assurance







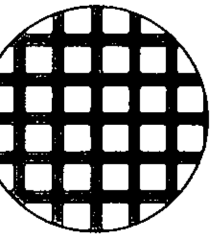
Intensive trials on simulation test rigs, together with fatigue tests that reproduce extreme loads, have demonstrated the very high product quality of OBERLAND metal substrates.

Quality-assurance checks carried out by independent testing institutes and experts have confirmed the durability of OBERLAND metal substrates under high mechanical stress and extreme thermal shock conditions.

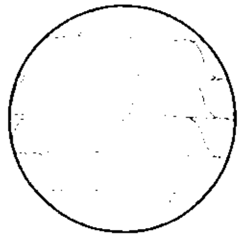
By adhering rigidly to our zero-fault philosophy, we create the prerequisites for high reliability and long life of our products.

System comparison

Comparison of metal and ceramic substrates



Ceramic substrate	Physical characteristics	Metal substrate
100 - 200	wall thickness, uncoated (μm)	30 - 50
100 - 600	N°. of cells per square inch (cpsi)	100 - 800
76 - 84	clear cross-section (%)	88 - 94
2.4 - 3.0	specific surface (m^2/dm^3)	2.8 - 4.2
410 - 600	specific weight (g/dm^3)	500 - 700
1.05	specific heat capacity (kJ/kg °K)	0.5
0.8 - 1.0	thermal conductivity (W/m °K)	14 - 23
62	heat quantity for temperature rising from 0 to 100 °C (kJ/dm^3)	30



The advantageous physical and technical characteristics of metal substrates yield favourable results with regard to catalytic conversion rate and engine power losses.

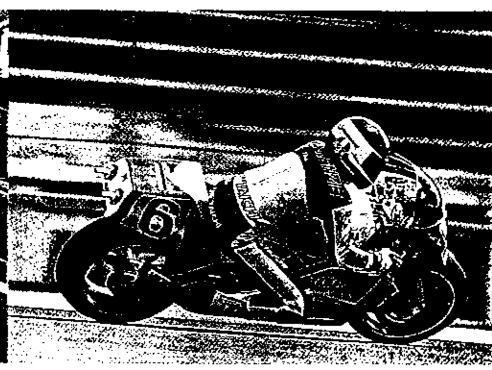
The metal wall is approximately 40 μm thick, producing a pressure drop some 60% lower than with a ceramic substrate of the same size.

This results in improved engine power and lower fuel consumption.

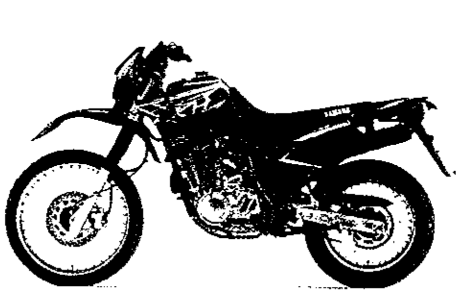
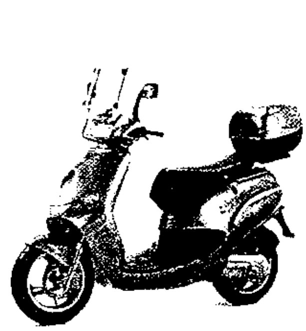
The larger clear cross-section and high specific surface of a metal substrate lead to much better catalytic activity.

The low specific heat capacity means that the metal substrate heats up more rapidly after a cold start, which improves the effective pollutant conversion rate.

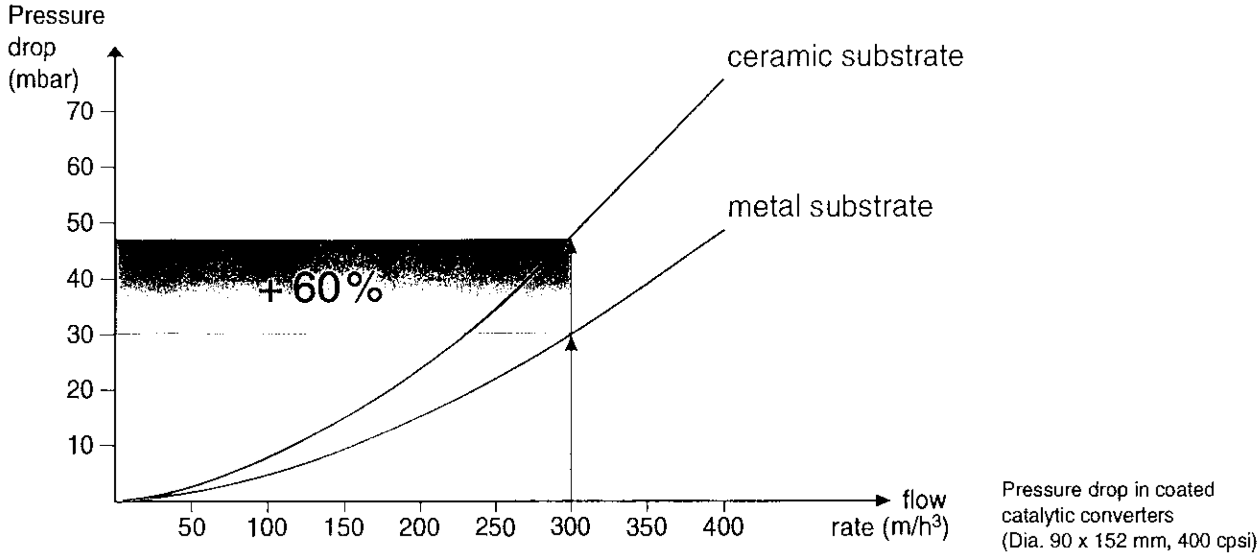
The considerably improved thermal conductance makes a metal substrate much less susceptible to short-term temperature peaks (e.g. after an engine misfire), and gives a rapid and even temperature distribution throughout the catalytic converter.



Comparison of pressure drop in catalytic converters



Metal substrates absorb tension and compression forces, and are therefore extremely resistant to mechanical vibration and thermal expansion.

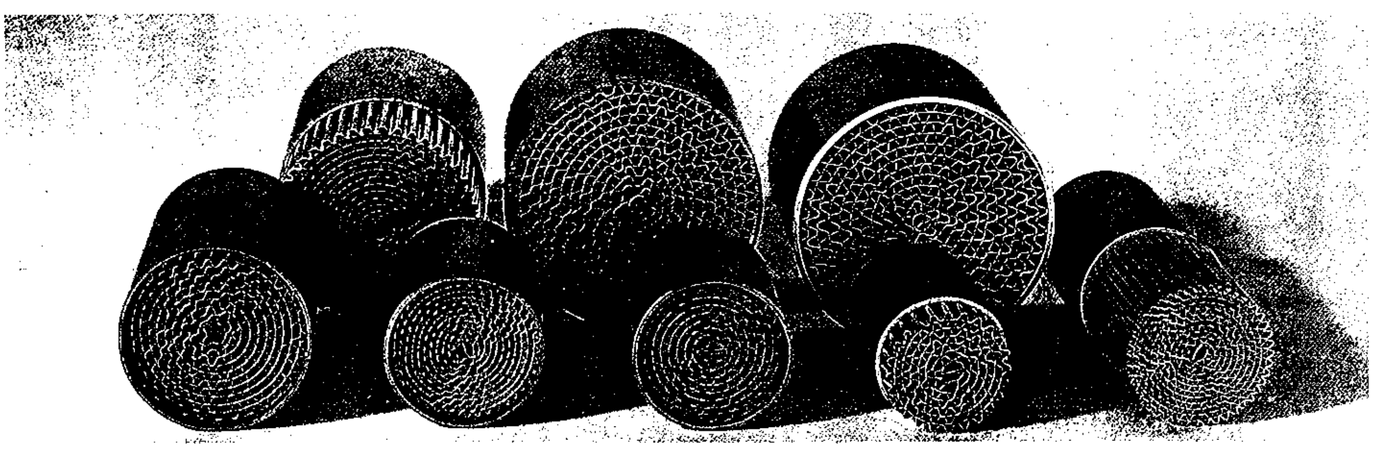
Owing to its very high thermal and mechanical stability, a metal substrate can be mounted very close to the engine and welded directly into the exhaust system – in contrast to a ceramic substrate.

Metal substrates permit a more compact catalytic converter, for the following reasons:

- extremely thin-walled cells
- high clear cross-section
- high specific surface
- no need of elastic embedding

Further advantages of metal-substrate catalytic converters:

- unlimited options for shape and dimensions
- high temperature resistance (up to 1300°C)
- high long-term strength and reduced susceptibility to faults



OBERLAND metal substrates are used in:

- cars and high-performance vehicles
- trucks and commercial vehicles
- motorcycles and mopeds
- stationary engines
- construction plant and machinery
- roasting, frying, and smoking
- marine engines
- selective catalytic reduction (SCR)

Oberland MANGOLD GMBH
Catalytic Converter Technology

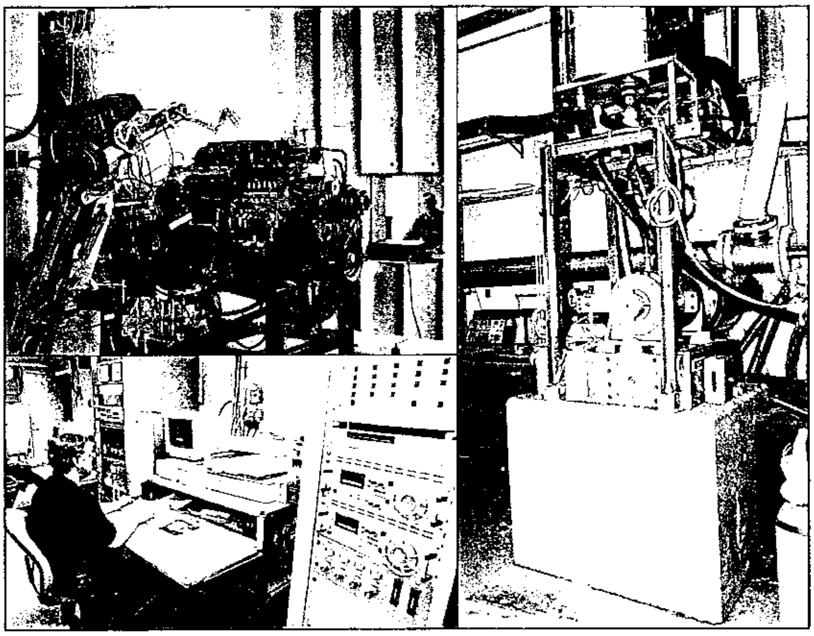
ESTEROL II

Annex 3

Luleå Tekniska Universitet/Laboratory for Research and Development in the environmental field.

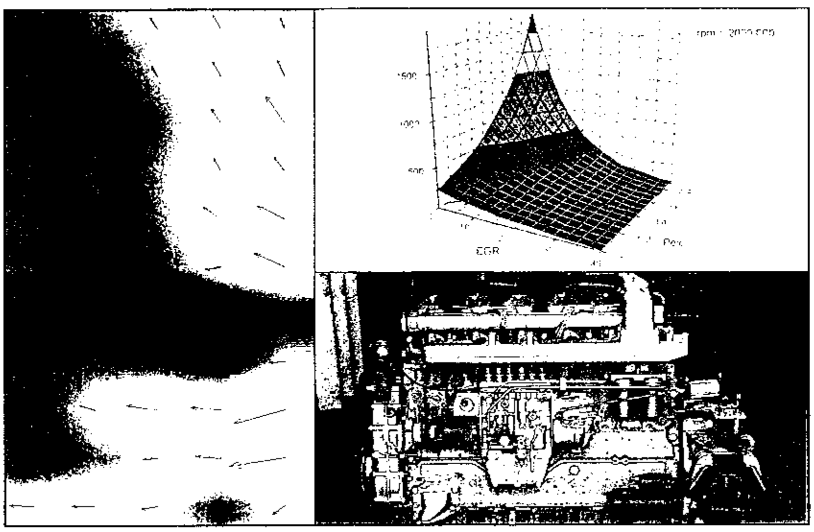
LULEÅ UNIVERSITY OF TECHNOLOGY
Department of Human Work Sciences
Physical Environment Technology
S-971 87 Luleå – Sweden
Phone +46 920 91000

RESEARCH AND DEVELOPMENT
Physical Environment Technology



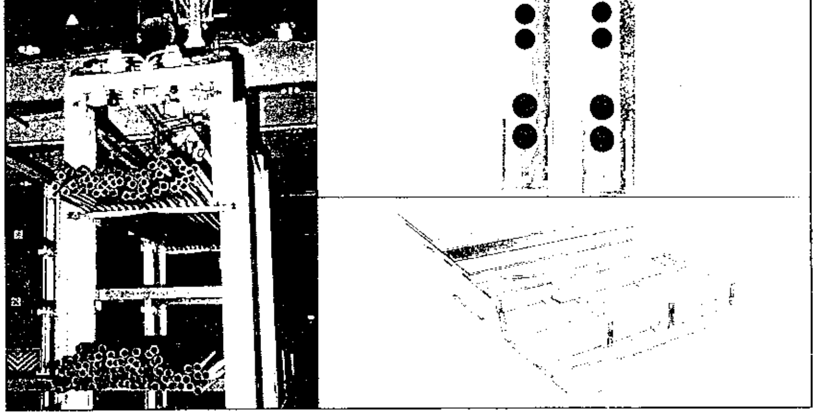
ENGINE EXHAUST EMISSIONS

- Exhaust gas measurement
- Catalytic tests
- Fuel tests
- Chemical analysis of unregulated exhaust gas emissions
- On-line exhaust gas measurements
- EGR controlled tests
- On-line multivariate control



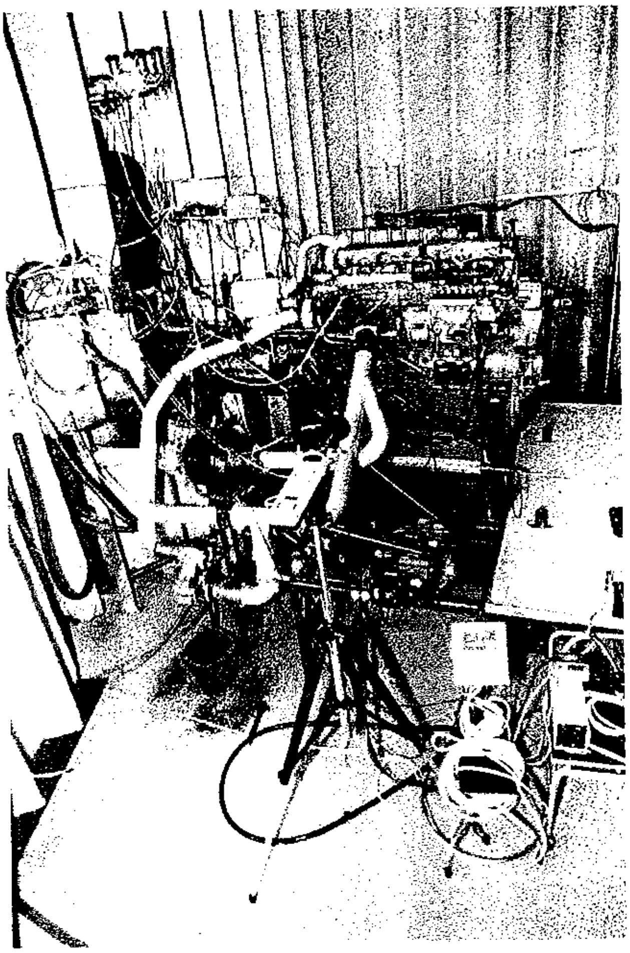
ENGINE NOISE AND VIBRATIONS

- SEA - Statistical energy analysis
- Modal analysis
- Sound intensity measurements
- Multivariate analysis
- Prediction of noise emission
- Combustion noise



INDUSTRIAL NOISE AND ACOUSTICS

- Material handling systems
- Industrial noise
- Whole body vibrations
- Building acoustics
- Sound quality
- Psycho acoustics
- Loudspeaker technology

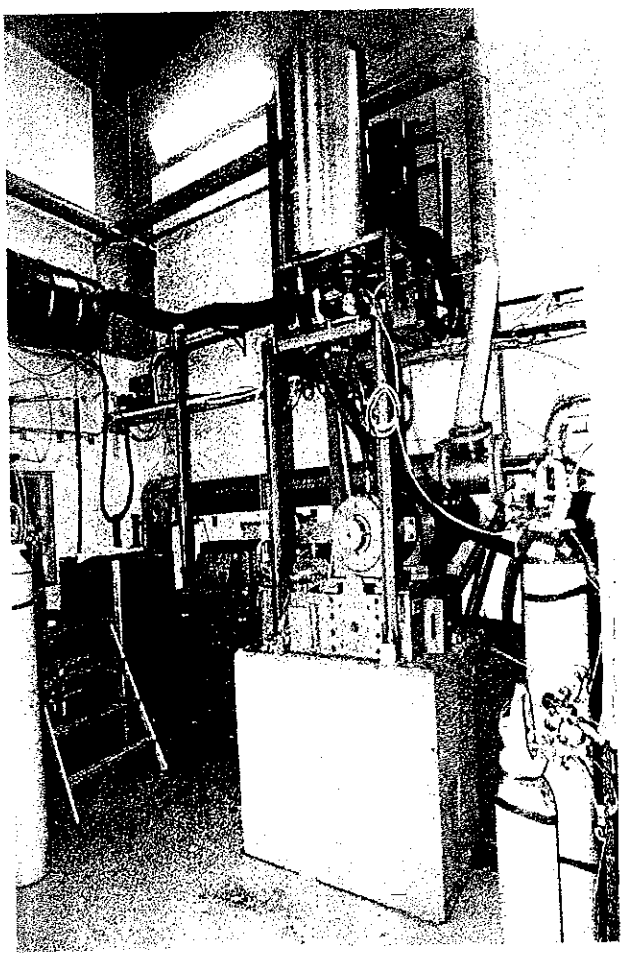


MOTORTESTCELL

Halvakustiskt rum
utrustat för
ljudmätningar och
avgasmätningar

vid

Motorlaboratoriet
Miljöteknik
Luleå tekniska universitet



MOTORBROMSRUM

Avskiljt rum från
testcellen med placering
av motorbroms,
avgassystem,
utspädningstunnel, motor-
kylsystem och ingassystem

vid

Motorlaboratoriet
Miljöteknik
Luleå tekniska universitet

LULEÅ TEKNISKA UNIVERSITET
Institutionen för arbetsvetenskap
Miljöteknik
S-971 87 Luleå - Sweden

1999-03-15

Miljöteknik - buller och avgasemissioner

Miljötekniks verksamhet har idag två huvudinriktningar: fysikalisk (akustisk) miljöteknik och kemisk miljöteknik. Avdelningen har sedan början av 1990 bedrivit forsknings- och uppdragsverksamhet inom motoremissionsområdet. Den gemensamma nämnaren är emissioner (buller och avgaser) från tunga motorer.

Forskningen inom "**fysikalisk**" miljöteknik bedrivs inom delområdena
1) Bulleremissioner från tunga fordon
2) Ljudkvalitetsforskning
3) Byggnadsakustik
4) Industribuller

"**Kemisk**" miljöteknik bedriver forskning och utveckling kring avgasemissioner från tunga fordon. Forskningen har under de senaste åren koncentrerats på
- Mätning och karakterisering av reglerade och icke-reglerade emissioner från tunga motorer körda på olika bränslen som; ren etanol , etanol/diesel, metanol/diesel och ren diesel.

- Emissionsbegränsande tekniker. Ett exempel är utveckling av system för avgasåterföring (EGR). Samarbete bedrivs även med KTH för utveckling av katalysatorer till fordon drivna med etanol och biogas.

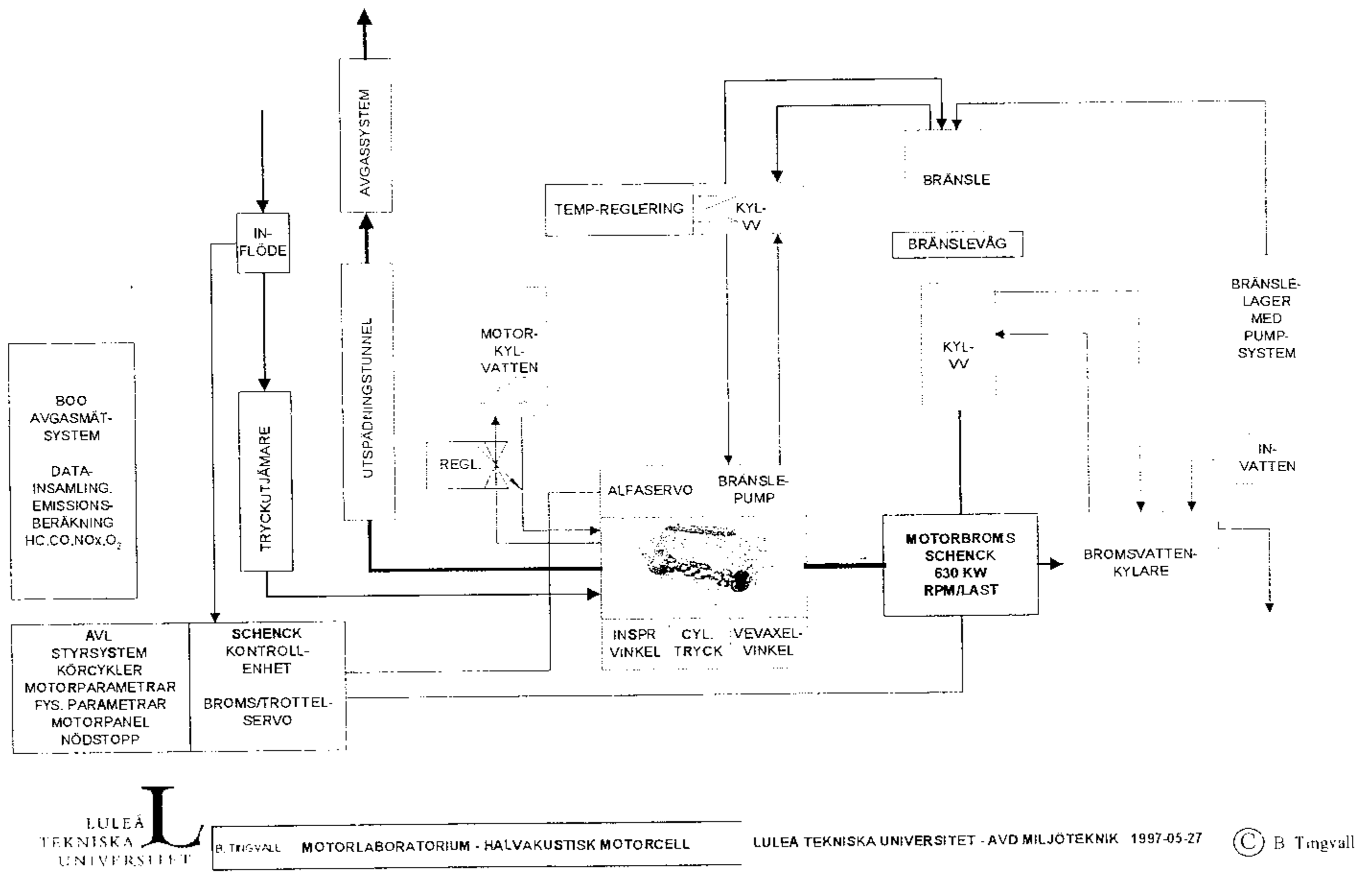
Forskningsområde

Målet för forskningen inom "kemisk" miljöteknik är att bidra till **utvecklingen av motorer och bränslen** som ger en **minimal miljöpåverkan** genom insatser inom områdena **avgasreningsteknik** och **karakterisering av emissioner.** Resultatet från verksamheten skall kunna utgöra underlag såväl för samhällets behov av framtida beslutsunderlag som för näringslivets (fordons- och motorindustrins) framtida behov av kompetensförsörjning.

Motoremissionslaboratoriet - kemilaboratoriet

Avdelningen för Miljöteknik förfogar idag över ett motoremissionslaboratorium med utrustning för provtagning och analys av både reglerade och oreglerade avgaskomponenter . Motoremissionslaboratoriet (och i anslutning därtill) kemilaboratoriet är utrustat med :

- Halvakustisk motorcell för mätning och analys av ljudemission, vibrationer och avgaser. Laboratoriet är utrustat med avancerade mät- och analyssystem för ljud och vibrationer.
- Motorprovbänk, Schenck hydraulbroms (630 kW) med styrsystem från Schenk och AVL.
- CVS-system med spädningstunnel för provtagning i avgaser som utspätts med luft.
- Chassidynamometer för biltester (fn ej uppmonterad, men kan iordningsställas).
- BOO avgasmätsystem med NDIR-analysatorer (Maihak UNOR 6N) för analys av CO och CO_2 Kolväten (HC) bestäms med en uppvärmd FID-analysator, VE 5 JUM . NO och NO_X bestäms med kemiluminiscens instrument Tecan CLD 700 EL.
- GC-FID, GC-MS och HPLC-UV för analys av icke reglerade organiska komponenter som aldehyder, etanol, ättiksyra, PAH och andra organiska emissioner av intresse.
- VOC-AIR Analyzer för analys av kolväten C2-C12 , ner till 10 ppt-nivå.
- Partikelmätsystem - fabrikat TSI
- Opacimeter, fabrikat Electracontroll



Annex 4

Cylinder pressure measurements.

1.1. Tryckpulsmätningar

Det utfördes tryckpulsmätningar och ljudmätningar med varierande varvtal och last. Syftet var undersöka hur det påverkas tryckpulsen och ljudnivå av Etanol med olika procent tändförbättrare. En detaljerat beskrivning om mätutställning kan ses i Fig. 1

1.2 Försöksuppställning

Försöksutställning med motor, tryckgivare, och optisk givare i nedanstående figur.

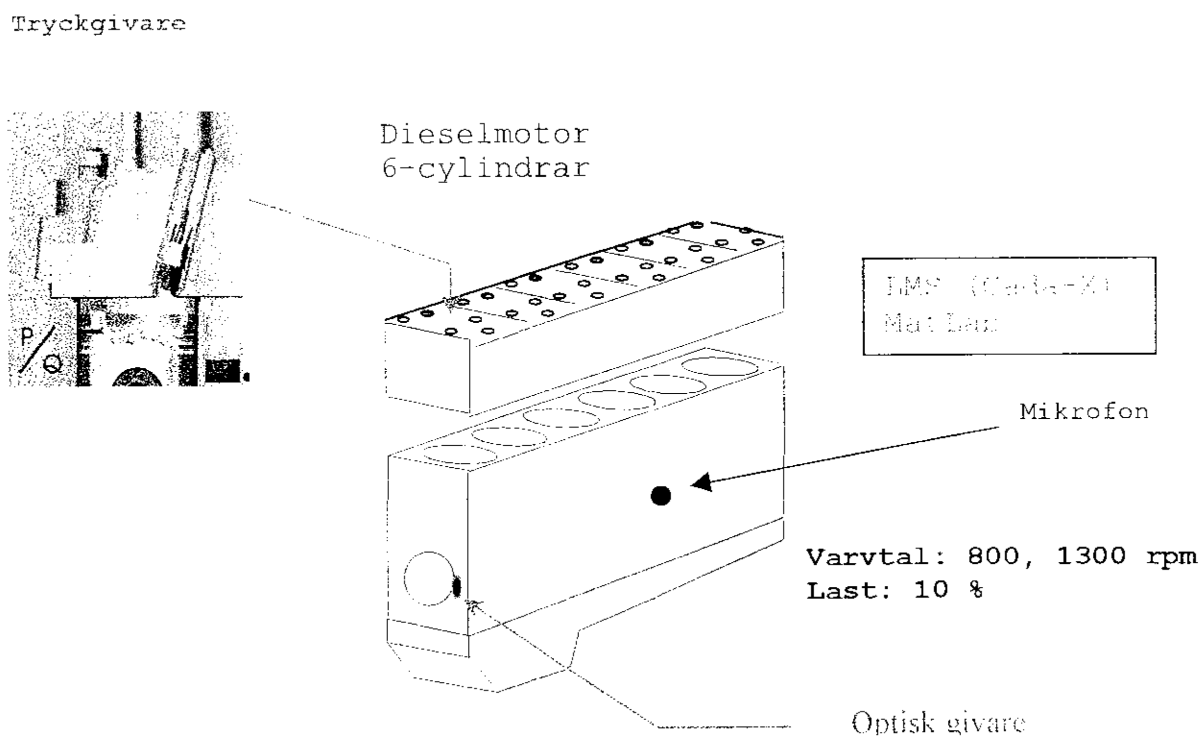
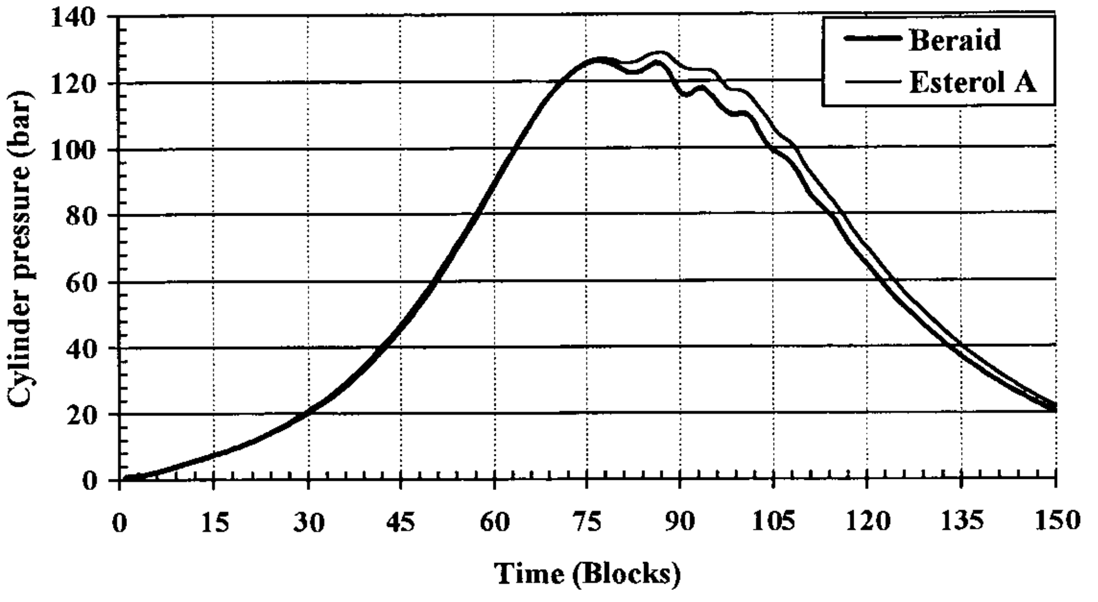
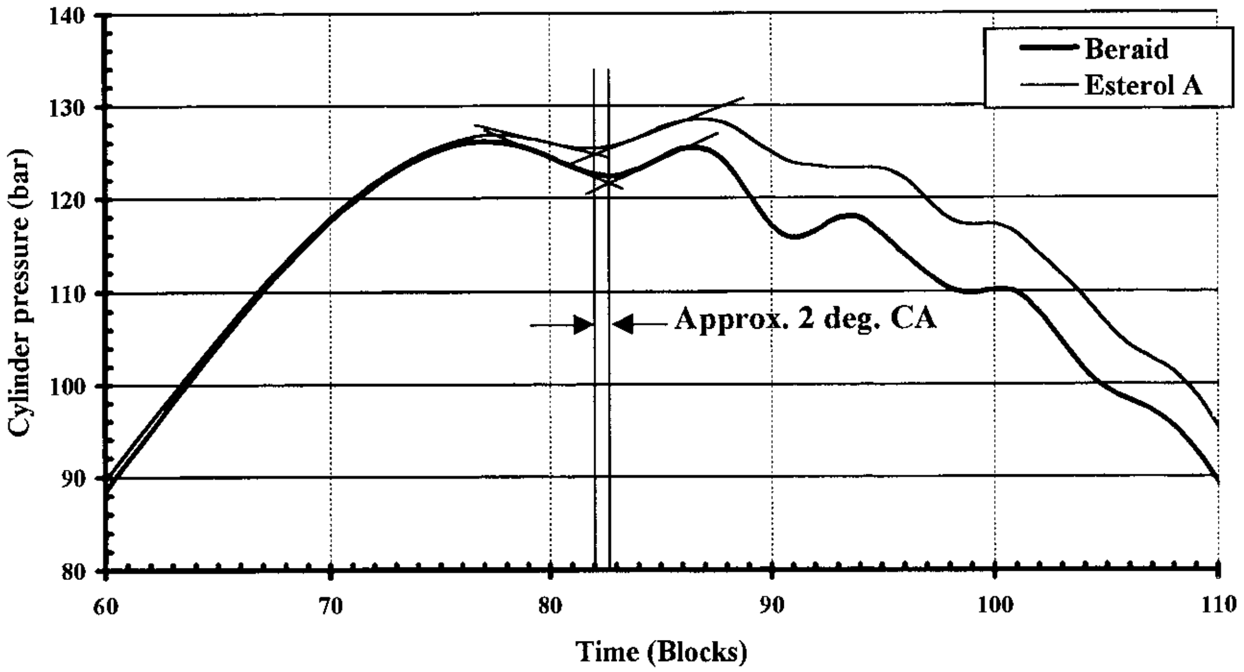


Fig 1: Mätutställning, 11 liters etanolmotor, mikrofon, optisk givare och tryckgivaren

Combustion chamber pressure at 90 % load, 1800 rpm



Deduction of the time point of ignition for Esterol A relative to the ref. fuel



Annex 5

Specifications of ethanol and RME (in Swedish)

Projekt: Etanol-rme
ELAB

Produktspecifikation

Etanol 95%

Leverantör: Sekab (Svensk Etanolkemi AB)
Levererad: 99-10-05
Etanolen innehåller denaturering och har använts till samtliga testkörningar.

			Analysmetod
Etanol	Volym-%	95.8	AMSE 1112
	Vikt-%	93.5	AMSE 1112
Densitet	g/ml	max 0.8084	SS-ISO 758
Utseende		Klar, inga partiklar	ASTM D 2090
Färg	Hazen	max 5	AMSE 1102
Vatten enl.KF	vikt-%	max 6.5	SS-ISO 760
Aldehyder (som acetaldehyd)	%	max 0.0025	AMSE 1118
Surhet (som ättiksyra)	%	max 0.0025	AMSE 1114

Säljaren garanterar också följande egenskaper, vilka ej analyseras vid varje leverans:

Vattenlöslighet vid 5%		fullständig	SS-ISO 1388-6
Destillationsintervall:			ASTM D 1078
-begynnelsepunkt	°C	min 77	
-torrpunkt	°C	max 79	
Metanol	mg/l	max 20	GC-metod, AMSE 1135
Finkel	mg/l	max 50	GC-metod, AMSE 1136
Flampunkt	°C	+ 12	SS-EN 22719
Indunstningsrest	mg/l	max 10	AMSE 1124
Explosionsgränser	vol-% i luft	3.5-15	Hämtat ur litteratur
Brytningsindex	n_D20	1.3630	-"-

STANDARDISERINGEN I SVERIGE
SWEDISH STANDARDS INSTITUTION

SVENSK STANDARD SS 15 54 36

Handläggande organ: Allmänna Standardiseringsgruppen, STG
Fastställd: 1996-11-27
Utgåva: 1
Sida: 1 (13)

Motorbränslen - Vegetabiliska fettsyrametylestrar - Krav och provningsmetoder

Automotive fuels - Vegetable fatty acid methyl esters - Requirements and test methods

0 Orientering

För att fettsyror från vegetabiliska oljor skall kunna anvädas som motorbräsle krävs att de omestras, d.v.s. får reagera med en alkohol (vanligen metanol eller etanol) till fettsyraestrar.

Försök pågår i flera länder att införa vegetabiliska fettsyrametylestrar t.ex. rapsoljemetylester (RME) som ersättigsbränsle för dieselbrännolja till snabbgående dieselmotorer, främst för fordon i tätortstrafik.

1 Omfattning

Denna standard omfattar krav på vegetabiliska fettsyrametylestrar till motorbränslen för snabbgående dieselmotorer, vilka är konstruerade för bränsle innehållande vegetabiliska fettsyrametylestrar. Med snabbgående dieselmotorer avses i denna standard motorer som presterar minst 16 varv per sekund vid ml belastning.

Standarden gäller endast för vegetabiliska fettsyrametylestrar utan inblandning i eller av andra bränslen. Standarden gäller vid leverans till den slutliga förbrukaren.

Bränslet omfattas i Sverige av myndighetsregler. Dessa ingår inte i standarden.

2 Referenser

ss 15 5180	Bensin - Bestämning av fosforhalt
SS-EN 116	Dieselbrännolja och eldningsolja - Bestämning av filtrerbarhet i kyla
SS-EN 22 719	Petroleumprodukter och smörjmedel - Bestämning av flampunkt i sluten degel enligt Pensky-Martens
SS-ISO 3104	Petroleumprodukter - Genomsynliga och ogenomsynliga vätskor - Bestämning av kinematisk viskositet och beräkning av dynamisk viskositet
SS-ISO 3170	Flytande petroleumprodukter - Manuell provtagning

Standarder kan beställas hos SIS som även lämnar allmänna upplysningar om svensk och utländsk standard
Postadress: SIS, Box 6455, 113 82 STOCKHOLM
Telefon: 08 - 610 30 00. Telefax 08 - 30 77 57

Upplysningar om sakinnehållet i standarden lämnas av STG
Telefon: 08 - 13 62 50. Telefax 08 - 618 61 28

Prisgrupp L

Tryck i mars 1997

NORSTEDTS TRYCKERI
TRYCKT PÅ PAPPER MILJÖMÄRKT MED SVANEN

SS-ISO 3171	Flytande petroleumprodukter - Automatisk provtagning ur rörledning
SS-ISO 5165	Dieselbrännolja - Bestämning av tändvillighet (cetantal) - Cetanmetoden
SS-ISO 6245	Petroleumprodukter - Bestäming av askhalt
SS-EN ISO 3675	Råolja och flytande petroleumprodukter - Laboratoriebestämning av densitet och relativ densitet - Areometermetod
ISO 660	Animal and vegetable fats and oils - Determination of acid value and of acidity
ASTM D 1744	Determination of water in liquid petroleum products by Karl Fischer reagent
ASTM D 3120	Trace quantities of sulfur in light liquid petroleum hydrocarbons by oxidative microcoulometry
ASTM D 4052	Density and relative density of liquids by digital density meter
ASTM D 5443	Paraffin, naphthene, and aromatic hydrocarbon type - Analysis in petroleum distillates through 200 C by multi-dimensional gas chromatography
DIN 51419	Testing of liquid fuels: Determination of total contamination in highly fluid petroleum products
IP 288	Sodium, nickel, and vanadium in fuel oils and crude oils by atomic absorption spectroscopy

3 Produktkrav

Krav rörande egenskaper framgår av tabellen i bilaga A.

För vissa av egenskaperna i tabellen finns inte standardiserade provningsmetoder, varför metodbeskrivningar för dessa ingår i standarden som bilaga B-D.

4 Provtagning

För manuell provtagning gäller SS-ISO 3170, varvid en provtagare av rostfritt stål skall användas. Provtagare av glas skall undvikas da detta stör analysen av fri glycerol genom att glycerolen fastnar pa glaskärlets väggar.

Provet skall innehålla ca 1l. Det delas upp så att en mindre mängd, ca **50** ml, avtappas i en separat flaska av polyeten eller polypropen med lock och resten i en glasflaska med lock.

5 Beteckning

En vegetabilisk fettsyrametylester avsedd för motorbränsle enligt denna standard anges med dess vegetabiliska ursprung följt av fettsyraesterns benämning, t.ex. rapsoljemetylester (RME). Efter bränslets benämning anges standardens beteckning, SS 15 54 36.

Bilaga A (Bindande)

Annex A (Normative)

Krav på vegetabilisk fettsyrametylester till motorbränslen

Requirement on vegetable fatty acid methyl esters for automotive fuels

Egenskapl *Property*	Enhet/ *Unit*	Krav/ *Requirement*	Provningsmetod/ *Test method*
Tändvillighet (cetantal), min. *Ignition quality* *(Cetane number), min.*		48	SS-ISO 5165
Viskositet vid 40 C *Viscosity at* 40 C	mm2/s (cSt)	3,5 - 5,0	ISO 3104
Densitet vid 15°C *Density at 15°C*	kg/m3	870 - 900	ISO 3675 ASTM D 4052
Flampunkt, min. *Flash point, min.*	°C	100	SS-EN 22719
Köldegenskaper [1] (CFPP), max. *Cold properties* [1] *(CFPP), max.*	C	-5	SS-EN 116
Svavel (masshalt), max. *Sulphur (mass fraction), max.*	%	0,001	ASTM D 3120 ASTM D 5453
Natrium (masshalt), max. *Sodium (mass fraction), max.*	%	0,001	IP 288
Kalium (masshalt), max. *Potassium (mass fraction), max.*	%	0,001	IP 288
Aska (masshalt), max. *Ash (mass fraction), max.*	%	0,01	SS-ISO 6245
Neutralisationstal, max. *Neutralisation number, max.*	mg KOH/g	0,6	ISO 660
Metanol (masshalt), max. *Methanol (mass fraktion), max,*	%	0,2	DIN 51413, T5
Fri glycerol (masshalt), max. *Free glycerol (mass fraction), max.*	%	0,02	Enligt bilaga B

Egenskap/ *Property*	Enhet/ *Unit*	Krav/ *Requirement*	Provningsmetod/ *Test method*
Monoglycerider (masshalt), max. *Monoglycerides (muss fraction), max.*	%	0.8	Enligt bilaga C
Diglycerider (masshalt), max. *Diglycerides (muss fraction), max.*	%	0.1	Enligt bilaga C
Triglycerider (masshalt), max. *Triglycerides (muss fraction), max.*	%	0.1	Enligt bilaga C
Fosforhalt, max. *Phosphorus content, max.*	mg/l	10	ss 15 5180
Jodtal, max. *Iodine number, max,*		125	Beräkning enligt bilaga D
Vegetabilisk fettsyrametylester (masshalt), min. *Vegetable fatty acid methyl ester (muss fraction), min.*	%	98.0	Enligt bilaga C
Vatten (masshalt), max. *Water (muss fraction), max.*	%	0.03	ASTM D 1744
Partikelinnehåll, max. *Particulate mutter, max,*	mg/kg	20	DIN 51419
Utseende *Appearance*		Klar och utan fällning *Clear and without sediment*	Okulärkontroll *Visual inspection*
Oxidationsstabilitet[2], max. *Oxidation stability[2], max.*			

Anmärkningar
1. Kraven i tabellen gäller generellt och är det naturliga CFPP-värdet. Vid behov av lägre CFPP-värde kan CFPP-nedstättande additiv tillsättas.
2. Provningsmetud för oxidationsstabililet hos vegetabilisk fettsyrametylester finns inte, varför inget krav kan anges. Metod är dock under utarbetande. Hållbarheten hos produkten är begränsad varför användaren bör uppmärksamma produktens hållbarhet.

Annex 6

"Esterol, a biofuel blend with esterified vegetable oil and bioethanol, as a more environmentally benign motor fuel", Paper presented at ISAF XIII, International symposium on alcohol fuels, Stockholm 3-6 July 2000, including the auditor's copy of oral presentation at the symposium.
(The paper covers mainly the Esterol I project, cf. ref. 1)

"Project Esterol", a European Altener project for the development and demonstration of "Esterol fuel", a biofuel blend with esterified vegetable oil and bioethanol, as a more environmentally benign motor fuel.

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Abstract

The principal objective of the project has been to demonstrate and develop "Esterol" (a blend between methyl esterified rapeseed oil (RME) and ethanol) as a more environmentally benign transport fuel for Europe. It has also been essential for the Esterol fuel idea to feature maximal compatibility with present day infrastructure in the transport market (no change of engines and vehicles, minor change of fuel distribution, storage and filling systems) in order to minimise problems of market acceptance of the new fuel formula. Successful demonstration of the fuel potential would then, it was thought, enable almost immediate large-scale use of Esterol in Europe with ensuing benefits for the environment, human health, labour and enterprise. Furthermore, Esterol fuel use is neutral in respect of the greenhouse gas effect and would, therefore, help Europe to achieve set goals in accordance with the Agenda 21.

The project's objective was to be met by the implementation of the following program:

1) Laboratory investigations of Esterol fuel in order to secure the optimum fuel formulation in respect of composition and physical characteristics and properties
2) Fuel testing in an engine laboratory. Investigation of performance characteristics of selected blend fuels in typical compression ignition engines (emphasis on heavy-duty engines for public transport buses).
3) Exhaust gas characterisation and analysis at an independent laboratory.
4) Fleet tests with, preferably, public transport buses in some cities and towns.

The results as obtained confirm the expectations in regard of the environmental issues and, also, regarding the general technical feasibility of Esterol fuels for ordinary, non-dedicated diesel engines in heavy-duty vehicles. The fleet test program, which was carried out to a limited extent, could, accordingly, be implemented without driveability problems occurring. Other, unexpected problems.did occur, however, demonstrating certain market acceptability problems. Accordingly, the smell of the exhausts from vehicles not equipped with catalytic converters appeared to be one of the most important problems for market acceptance. The need to apply efficient catalytic exhaust emission converters at the engines' tailpipes is, therefore, anticipated.

The project has been financially supported by the European Altener program, and by NUTEK, the national Swedish authority for technical development. The extension of the project is financially supported also by the Swedish Energy Authority and by the Swedish Communication Research Board (KFB).

1 PROJECT RATIONALES

1.1 Background and prerequisites

The transport sector in Europe seems to be the only economic sector in which there has been no substitution on a commercial scale of fossil, petrol fuel by other energy products. However, demonstrations of biodiesel use for motor vehicles in Europe have been undertaken during recent years and on a reasonable, relatively large fleet pilot and demonstration scale (especially in France). In these projects, large oil companies have participated in the role as suppliers of blends between gas oil (diesel fuel) and rapeseed oil. Accordingly, many thousands of vehicles have been running on such fuel representing use of some hundred thousands of m^3 of vegetable oil ester. The use of neat biodiesel has also been, and is being, demonstrated in some countries (e g Sweden), though on a smaller scale.

Increased production and use of renewable energy in Europe is, more generally, highly motivated due to the beneficial effects this have been assessed to have on (especially in the long term) European economy and environment. Social benefits have also been particularly emphasised. Accordingly, the urgent need to efficiently abate further degradation of the employment situation in Europe has been pleaded to constitute a very strong motivation for large-scale exploitation of renewable energies and of biomass in particular. This would have the long term potential to substitute for crude oil import and for progressive absorption of the total foreseen unemployment in the agricultural sector of the Union. Accordingly, no less than 4-7 Millions out of 9 Million people totally employed in case of a large scale exploitation of renewable energies, have been estimated to be 'new jobs', with additional (tax) incomes in the order of some 140 Milliard Euro. Consequently, unemployment subsidies could be reduced by the amount of some 50 Milliard Euro and, in addition, the benefit from the improved balance of payments due to the decreased energy imports would amount to some 5 Milliard Euro. Accordingly, the total benefit for Europe have been estimated to be some 195 Milliard Euro, which leads to the conclusion that the social advantages of substituting imported energy with domestic European energy could justify a price of such energy, which is considerably higher than that of the conventional, fossil fuels being substituted (2).

1.2 The prospect of using a blend of FAME (RME) and ethanol ('Esterol') as fuel for ordinary, non-dedicated CI engines.

By blending Rape seed oil Methyl Ester (RME or, more generally Fatty Acid Methyl Ester, FAME; the acronyms FAME and RME will be used interchangably with "biodiesel" below) and bioethanol it would be possible to obtain fuel formulations which do not feature the disadvantages of each one of the individual, neat fuel formulations. On the contrary, such blend options (here below called "Esterol") would combine the virtues of both neat options. Therefore, blending RME with ethanol could then be expected to have the following advantages in comparison to diesel fuel:

- Lower emissions of regulated components (including NO_X).
- Lower emissions of unregulated emissions like PAH, aldehydes (by two-way catalysts).
- Potential alleviation of fossil-based greenhouse gas emissions.
- Enhanced possibilities to apply oxidative, two-way catalysts to the exhausts.

Esterol formulas would also feature some advantages relative neat ethanol fuels like:

- Higher heat content.
- Better lubrication properties.
- Lower price.
- No need to use dedicated engines.

In view of the expected advantages to be achieved, it would appear interesting to formulate a renewable fuel for ordinary, non-dedicated vehicles for e g inner city traffic and transport. Such a fuel could feature the prospects of being superior in most respects to most other CI engine fuel alternatives with similar availability in the near and medium term. The project would then serve the purpose of finding an optimal composition of such a blend fuel and to test and to demonstrate its feasibility of use.

2 PROJECT OBJECTIVES.

In view of the rationales of the project, its objectives could be described as follows:

- Definition and characterisation of efficient blends between RME and ethanol ("Esterol").
- Testing and demonstration of the feasibility for use of Esterol in diesel engines.
- Field testing of the feasibility to use Esterol fuel in heavy duty vehicles.
- Demonstration of the environmental benignity of using Esterol fuels.

In consideration of these objectives a pertinent technical program was set up and implemented.

3 RESULTS.

3.1 Blend fuel investigations.

The Investigations were undertaken in a number of different laboratories such as

- the Analysis Centre of Karlshamn Sweden AB (vegetable oil factory, which is accredited by appointment by the Swedish Board for Technical Accreditation).
- Saybolt Sweden AB.
- SGS Sweden AB (a Redwood Petroleum and Petrochemical Services company).
- University of Hohenheim, at "Landesanstalt für lantwirtschaftliches Maschinen und Bauwesen" (near Stuttgart, Germany).

The results of the work confirmed that the fuel blends could be deemed to be appropriate as fuels for diesel engines. Notably, in a work at the University of Hohenheim did Esterol-20 (RME with 20 vol-% of ethanol) virtually come out as one of the very best alternatives out of several tested, alternative fuel blends (1). Accordingly, only two out of several fuel blend formulations under testing were deemed to be good enough to justify long-time engine testing, and one of those two was Esterol-20.

The results from the fuel characterisations and analyses undertaken are given in table 1 below.

One striking feature of all of the Esterol blends is that the flash point falls to levels close to that of neat ethanol, which will have consequences for proper and safe storage and handling of the fuel. Other features are that the cold temperature properties of the blends seem to be dominated by those of pure RME and to be rather unaffected by the ethanol content of the blends. It was also found that the CFPP point varied from about -10 down to -23 °C respectively for different samples being analysed at the three different laboratories being used. The causes of these different results are, conceivably, the individual, characteristic features of the different RME samples (stemming from different sources and suppliers) being analysed.

A sample of Esterol-20 has been analysed at the University of Hohenheim, Germany, regarding crucially important motor fuel parameters. The objectives were to study possibilities and options to improve on biodiesel in order to determine how to meet necessary quality requirements for trouble-free use in modern CI engines (1). A number of various blend fuel formulas were then studied and among them was Esterol-20. Subsequently, comparisons were undertaken between the various blends in order to reach a selection of those compositions, which could be deemed to be best as fuel for CI engines. Esterol-20 was one out of three possible formulas, which could be selected as suitable substitutes for fossil diesel oil.

Tests were also carried out in regard of plastic material compatibility of Esterol blends. Satisfactory and materially compatible materials were found.

Table 1: Comparison between neat FAME (RME) and Esterol-20 fuel (SGS and Univ of Hohenheim).

Test	Unit	FAME fuel	Esterol-20	RME Spec.
CFPP	°C	0/-10/-20	-16--23	< -5
Density at 15 °C	g/cm^3	0,875-0,900	0,870	0,870-0,900
Viscosity at 40 °C	cSt	3,5-5,0	3,1	3,5 - 5,0
Flash Point (Abel)	°C	>110	17,5-19	> 100
Carbon Residue Micro	% mass	0,05	< 0,04	
Ethanol Content	% vol.	--	20	
Sediment by extr.	% mass	ASTM D 473	< 0,01	
Water Content	mg/kg	< 300	10500-13000	
Cetane NR	--	>49	48	48
Energy Content	MJ/kg	37,5	34,6	
Energy Content	MJ/dm^3	33,3	30,0	

Esterol-20 was, after these measurements, deemed suitable as fuel for ordinary CI engines. Contributing to this conclusion were the following properties of Esterol-20:

- Low viscosity, which enables smaller fuel droplets to be formed in the combustion chamber with, ensuingly, improved combustion of the fuel.
- Low CFPP point will secure good winter properties.
- Improved exhaust gas characteristics. The prospect of achieving lower NO_X emissions (as compared with neat RME) was particularly appreciated.

3.1.1 Determination of the cetane nr of Esterol fuels.

The cetane numbers were determined at the laboratory of SGS Sweden AB by using a CFR cetane engine and applying the ASTM D 613 method. The results are depicted in diagram 1 below.

The conclusion from these measurements was that the preferred content of ethanol in an Esterol fuel blend should be 20 vol-% ("Esterol-20"). Such a fuel formula would enable safe cold starting conditions for ordinary CI engines without having to additivate the blend further with a particular chemical substance in order to further ease ignition. Ignition enhancement would, however, be necessary for higher ethanol contents. The advantages to be obtained by the Esterol-20 blend then would include the possible achievement of a low selling price while deriving benefit by the superior environmental properties of the ethanol component.

3.2 Engine lab investigations.

Engine lab investigations have been carried through with emphasis on exhaust gas emissions and driveability. A comprehensive program was implemented by testing a normal Volvo city bus on a chassis dynamometer at Volvo Aero Turbines Company ('VAT') in Malmö, Sweden. The bus engine was a Volvo TD 102 as equipped with a manual gear box. Special adaptation to RME had not been implemented prior to testing. Accordingly the bus had to be compared with the engine as optimised for fossil diesel oil.

The exhaust gas emissions were measured by using a special 'Road Load Curve' according to VAT standard procedures to simulate driving on a road on level ground. The test program as carried out included the fuels and fuel blends as given in Table 2 (below). The test

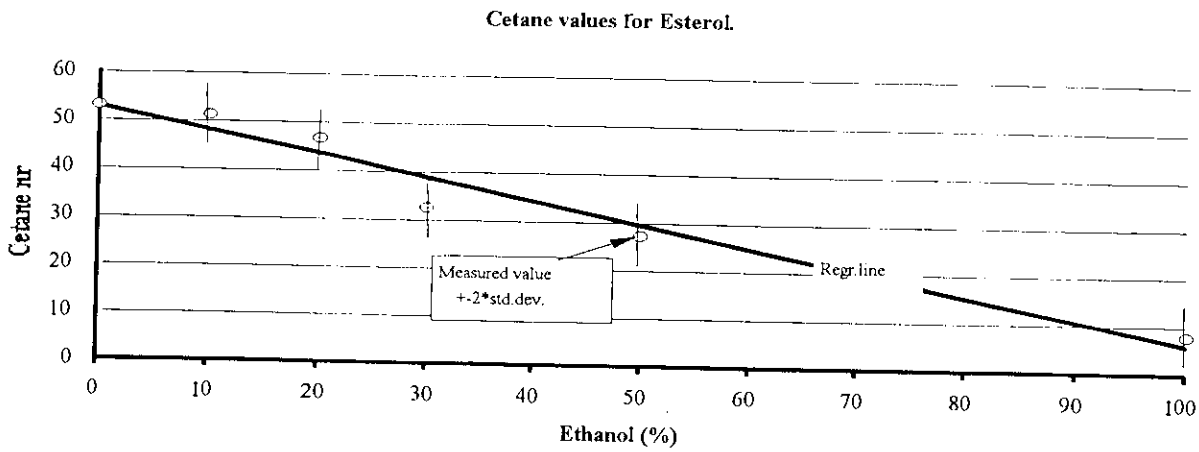

Diagram 1: Cetane numbers vs ethanol content.

program also included one cold start test of Esterol-20 at low ambient temperature. The regulated exhaust gas emissions (CO, HC, NO_X and particulates) were measured. Exhaust gas emission data for the various fuel compositions were obtained, using the test method as described for the fixed speeds 0 - 60 km/h. Weighting factors used for averaging over the VAT test cycle are given in table 3.

Table 2: Fuels selected for exhaust gas emission analysis

Fuel	Fuel composition	Notes
RME	Neat fuel	Ref. fuel no 1
Diesel MK1(*)	Aromatics < 5 v/v Sulphur < 0,001 w/w	Swedish 'Class 1 diesel', Ref. fuel no 2
Esterol-10	RME+10% ethanol	
Esterol-20	RME+20% ethanol	
Esterol-30	RME+30% ethanol	+0,6% of ignition improver
Esterol-50	RME+50% ethanol	+2% of ignition improver
Esterol-75	RME+75% ethanol	+4% of ignition improver

*) Specification according to the Swedish standard.

The exhaust gas emission data obtained for NO_X over the VAT road load cycle reveal, that NO_X emissions decreases with increasing ethanol content as depicted below in diagram 2.

From diagram 3 it then becomes obvious that the principal differences between the emission levels of NO_X for the various fuel compositions are found at idling conditions. Because idling is a rather characteristic feature for city driving with many halts during a duty cycle, emissions at a bus stop will affect significantly the overall test cycle data as obtained by weighting over city driving modes due to the high weight factor for idling (0,25 according to table 3). Therefore, the overall VAT cycle values for all of the fuels as tested are found to be larger than any one of the empirical emission data obtained at anyone of the various individual, specific VAT cycle speeds (10 - 60 km/h). Considering that idling occurs mainly at bus stops in city traffic, comparisons between emission levels of NO_x at bus stops for different fuels are particularly interesting. Accordingly, it was found that Esterol-20 were some 15% better at idling than neat RME, and roughly equal with diesel MK1.

Table 3: Speed weighting factor for VAT road load cycle data.

Speed (km/h)	**Weight factor**
0	0,25
10	0,07
20	0,08
30	0,25
40	0,17
50	0,13
60	0,05

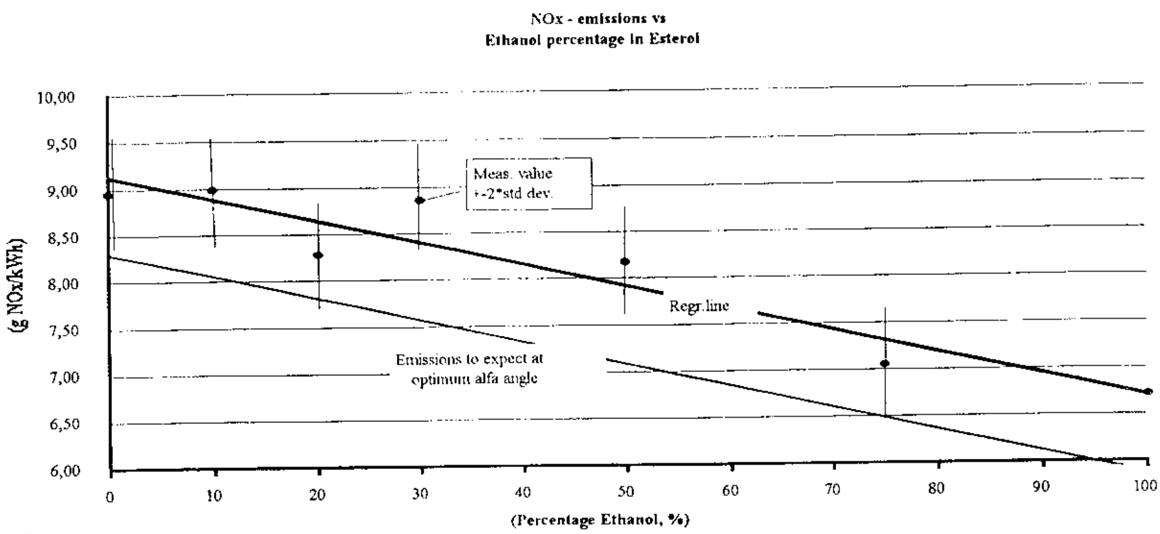

Diagram 2: NO_x emissions vs ethanol content in Esterol blends.

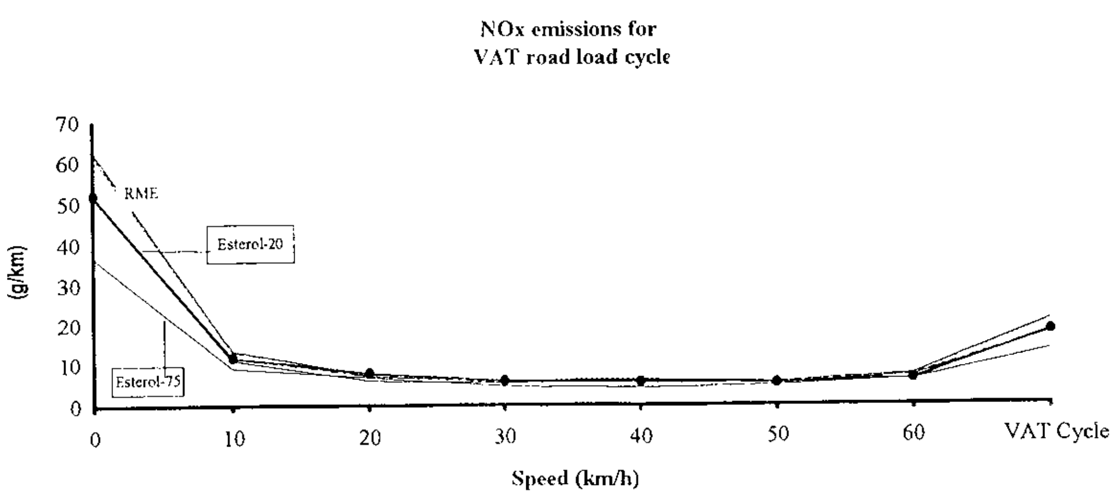

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Diagram 3: NO_X emissions vs. speed

While the exhaust gas emission levels of NO_X were found to decrease by increasing the ethanol content in Esterol fuels, the emission levels both of CO and HC increase somewhat as depicted in diagram 4 below. Further, what was said above regarding the rather high levels of exhaust gas emissions of NO_X (for all fuels as compared) at idling also applies to the emissions of CO and HC. Remedial measures for CO and HC would then be to apply oxidative, two-way catalysts with low light off temperatures to the exhausts.

Finally, smoke emissions have also been measured. It was then shown that the smoke levels decrease drastically while increasing the ethanol content in Esterol. This applies especially to idling conditions, at which Esterol-20 produces only half as much smoke than the best diesel quality (Swedish MK1 fuel).

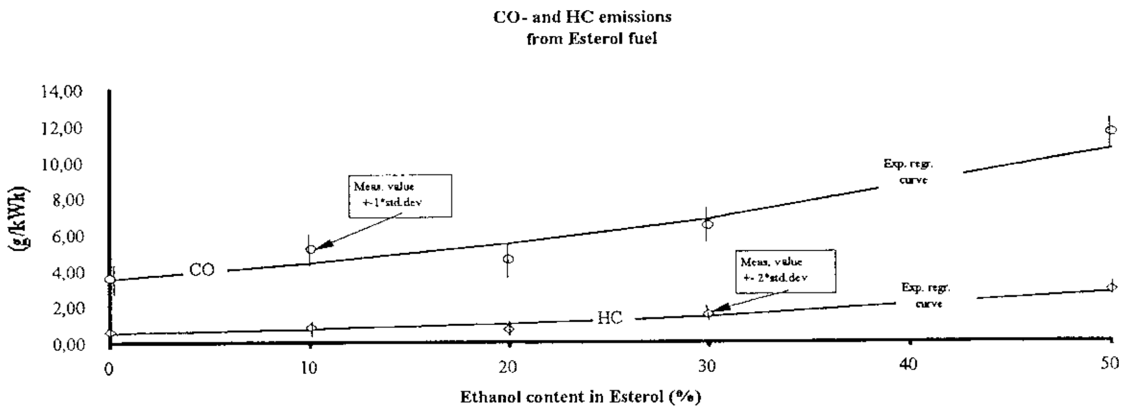

Diagram 4: CO and HC emissions of Esterol fuels.

3.2.1 Discussion and conclusions.

The exhaust gas emission analysis as carried out seems to confirm the initial expectations of lower overall NO_X emissions for Esterol fuels as compared with neat RME. The NO_X emissions for Esterol-20 were also shown to emulate the emissions for the best diesel MK1 fuel in spite of the fact that the comparisons favoured MK1 for which fuel the test vehicle was optimised.

Overall VAT cycle data on CO and HC emissions increase marginally as compared with RME due to the decrease of ignition quality with increase of ethanol in Esterol.

Table 4: Regulated exhaust gas emissions of Esterol-20 as compared with RME and MK1, VAT test cycle.

Exhaust emission component	Esterol-20 (g/kWh)	RME (g/kWh)	MK1 (g/kWh)
NO_X	8,3 ± 0,3	9,0 ± 0,3	8,3 ± 0,3
CO	4,6 ± 0,9	3,6 ± 0,9	3,3 ± 0,9
HC	0,76 ± 0,17	0,61 ± 0,17	1,21 ± 0,17
Smoke	0,1(*)	0,14(*)	0,20(*)

(*) Bosch units

Unregulated exhaust gas components like formaldehyde and acetic aldehyde should also be measured as well as acrolein and polycyclic hydrocarbons. Such measurements were not included in the program so far carried through. Some evidence from the literature reveals, however, that aldehyde emissions are increased somewhat for RME as compared with conventional diesel fuels, while PAH values would decrease considerably (1). Particulate emissions ('white smoke') have been reported to increase with RME, while the genotoxicity of such increase of particulate emissions has been shown (by Ames testing) to be much lower than for particulate emissions from diesel fuel of fossil origin (1).

Now, the emissions data obtained for Esterol-20 obviously emulate neat RME and the best diesel fuel in Sweden as follows from table 4 (above).

3.2.2 Tests at VTT Technical Research Center of Finland.

Facing a need to enable more generally valid exhaust gas emission comparisons to be established for different fuels, it becomes necessary also to use test methods, which are more general and internationally well-known. Therefore, tests were carried out at VTT, Finland, using the ECE R49 test method. A Euro 2, Volvo engine (DH10A-285, featuring 210 kW at 2000 rpm and a compression ratio of 20:1, turbocharging and direct injection) was used while comparing the same fuels as previously tested. Testing was then carried out both with and without compensation for the late ignition of Esterol-20 fuel.

3.2.2.1 Results and remarks.

The maximum power obtained with MK1 fuel was 190 kW at 2000 rpm and the maximum torque was 1100 Nm at 1450 rpm. The power loss obtained with the Esterol-20 fuel was about 20% relative to MK1. In order to improve on the engine performance when fuelled by Esterol-20, injection started about 2 degrees earlier relative to the setting for MK1. Testing

Table 5: Results of the exhaust gas emission testing according to the ECE R49 test procedure with the VOLVO DH10A-285 engine. Accuracy of measurements: +-5%.

Fuel	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	Particles (g/kWh)	CO_2 (g/kWh)	Fuel consumption (g/kWh)	Bosch smoke
Euro II Requirement	4,0	1,1	7,0	0,15			
MK1	0,56	0,18	5,5	0,095	682	229	0,44
Esterol-20	1,22	0,26	6,2	0,135	712	287	0,05
Esterol-20, stand. sett.	1,12	0,23	5,9	0,094	719	289	0,05
Esterol-20 -1,7 °CA	0,80	0,18	6,6	0,077	706	283	0,05
RME	0,52	0,07	7,2	0,066	688	260	0,12

*) average value without weighting factors

the engine in accordance with this recipe was also finally undertaken, what resulted, as expected, in a more stable engine performance. The exhaust gas emission levels for the three different fuel formulations (MK1, neat RME and Esterol-20) are depicted in Table 5 (above).

3.3 Field tests.

Field testing of a city bus was carried through in Helsingborg, Sweden, in 1998. A new Volvo bus featuring model year 1998 (vehicle type B10L as equipped with a 10 litre, direct injection diesel engine of the most modern type) was tested in regular city duty. Prior to the start up of the field test, the compatibility between fuel and the material of the fuel system of the engine was secured. In spite of this, some problems occurred due to inadequate tubing material in the front end of the fuel line (at fuel storage). The conclusion is that Esterol blends feature higher dissolving power than both fuel components making it necessary to choose materials (to be exposed to Esterol) with care.

A larger "hinge-bus" (Scania make) with larger passenger capacity was also tested on Esterol-20. This bus featured engine fuel system materials, which could better stand exposure to the Esterol fuel than the first Volvo bus. Furthermore, it was equipped with a catalytic (oxidative) exhaust gas converter to abate unpleasant smells at cold start and operation at low load. The catalyst was also intended for the reduction of all other noxious, burnable exhaust gas components. Technical problems and problems of drivability were not encountered in this case. Further, neither did previously experienced "bad" smell from the exhausts appear due to the effect of the catalytic converter used.

The fuel consumption for the two test buses was found to be lower than what could be expected from the nominal differences in heat contents between the different fuels assuming the same energy efficiency. Accordingly, the engine efficiency seems to be somewhat (about 5 %) higher with Esterol-20 fuel than with MK1.

After having alleviated the technical problems associated with the Esterol-20 fuel, some other problems of non-technical character appeared, however. Operational, maintenance personal complained about unpleasant smell of the exhausts, especially while cold-starting the engines in the garage. They also complained about headaches and claimed these problems to be alleviated before the RME-based fuel could be accepted.

Such problems are not new. Complaints of similar character have been reported from other countries and not only for biodiesel use but also for conventional diesel oil exhausts as well. They have been subject to scientific investigations, according to which effects on exposed people of exposition towards biodiesel exhausts and towards conventional diesel oil exhausts have been compared. Crucially important restrictions for the lung functions of exposed people were not found to follow from such exposures. However, improvements can be obtained through use of pertinent catalysts. Such catalysts have been developed in Germany and are readily available.

Field testing of garbage trucks, entrepreneurial machines and of street cleansing vehicles has been carried out in Stockholm. The vehicles tested were the following:

- Two garbage collecting trucks in regular duty in Stockholm.
- Three heavy-duty trucks in various duties (street cleansing, street construction work)

The storage and filling station was specially designed for alcohol containing fuels and featured by "above ground" location.

The technical feasibility of using Esterol-20 in these vehicles was confirmed. No loss of driveability properties of the vehicles has, accordingly, been experienced and the fuel consumption seems also to have been normal (in energy terms). The pilot infrastructure (including storage and filling) has operated well according to expectation.

In spite of the technical feasibility of Esterol-20 driving, the acceptance by the operators (driving, maintenance) of Esterol-20 driving has been hesitant when using the fuel in certain types of operations. Especially, for applications such as street work (e g digging machines operating at one place for some extended time period during a whole day) the personal operating near the machine for extended periods of time, have indicated some peculiar feelings ranging from bad smell (smell of frying oil etc) to headaches due to Esterol-20 driving. The problem is not new and has been reported in the literature especially for neat FAME fuel. It has been subject to careful studies (1). The conclusion is that it can largely be solved by equipping the vehicles with pertinent, oxidative catalytic converters, which will oxidise unburnt or partly burnt components of the fuel exhausts.

4. RME as ignition improver in neat alcohol fuels for dedicated alcohol diesel engines.

In an extension of the project to include the development and testing of a new, Esterol fuel formula for neat ethanol for use as an alternative, renewable diesel fuel for dedicated ethanol engines, it has been proved that RME can be used also as an ignition improver for ethanol. Accordingly, an efficient, new fuel formula has been developed and tested featuring the same superior exhaust emission characteristics as the "conventional" ethanol fuel as used in Swedish city bus fleets.

This extension of the Esterol project, which is still going on, has also been supported by the European Altener program, the Swedish Energy Authority and the Swedish Communcation Research Board (KFB).

5 CONCLUDING REMARKS

The principal idea behind the project, namely that use of a blend between RME (FAME) and hydrous ethanol as fuel for CI engines would be associated with lower levels of noxious exhaust gas emissions such as NO_X and smoke seems to have been (largely) confirmed. It has also been proven in tests as previously carried out that optimising the engine for RME (FAME) fuel instead of for conventional diesel oil would reduce exhaust gas emission levels still further.

Using clean fuels like Esterol-20, which is very low in Sulphur content and inorganic ash components as well, would also make it appropriate to consider application of oxidation catalysts for abating all kinds of noxious and combustible exhaust emission components. Such measures would decrease the CO and HC emissions down to levels which would be significantly lower than those which are obtained by using conventional Diesel oil (without catalyst) for the engine. It would also decrease the emissions of aldehydes down to very low levels.

The use of RME as ignition improver is the target action during the extension phase of the Esterol project. This project is still on-going, but the results so far obtained are very promising. Considerably lower price of the ethanol fuel, improved fuel characteristics and the same superior exhaust emission levels as for the "conventional" ethanol fuel hitherto used in Swedish buses, seem to be within reach.

6 LITERATURE

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2) W. Palz, G. Grassi, European Commission,
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ELAB
Engineering & Development Co.
Ecotraffic

Project "Esterol", a European Altener project for the development and demonstration of "Esterol" fuel

ISAF XIII, Stockholm, 2000-07-04
Egon Larsson, ELAB

NUTEK

Outline

- The prospect of using FAME/Ethanol blends
- Esterol I Project
  - Project aim and objectives
  - Implementation and results
  - Summary and conclusions
- Esterol II project
  - Project objectives
  - Project work program
  - Implementation and results
  - Summary and conclusions

The prospect of using FAME/Ethanol blends

Advantages:
- Alleviation of fossil carbon dioxide emissions
- No need to use dedicated diesel engines
- Lower exhaust gas emissions (than for FAME and diesel oil)
- Lower price of fuel (than that of neat ethanol)
- Enhanced raw material base for production

Disadvantages:
- Lower cetane NR (than that of fossil diesel and neat FAME)
- Some loss of power due to lower calorific value (than diesel oil and FAME)
- Lower flash point (than diesel oil and neat FAME)

Principal aim

- To demonstrate the efficiency of blending FAME with ethanol to alleviate the environmental disadvantage of FAME as fuel for CI engines relative to diesel EC1 fuel.

Project objectives

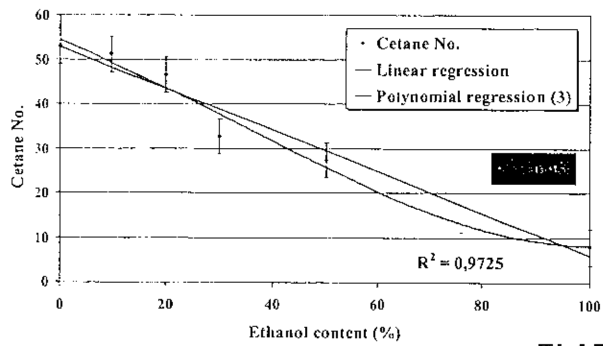
- Definition and characterisation of efficient blends between RME and ethanol ("Esterol")
- Testing and demonstration of the feasibility for use of Esterol in diesel engines
- Field testing of the feasibility to use Esterol fuel in heavy-duty vehicles
- Demonstration of the environmental benignity of using Esterol fuels

In consideration of these objectives, a pertinent technical program was set up and implemented

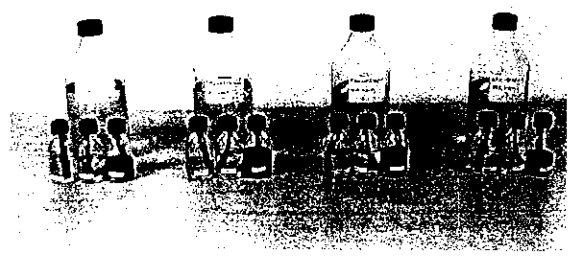
Fuel characterisation

Test	Unit	FAME	Esterol-20	RME spec.
CFPP	°C	0/-10/-20	-16 – -23	<-5
Dens. at 15°C	g/cm³	0,875 - 0,90	0,870	0,870-0,900
Visc. at 40°C	cSt	3,5 – 5,0	3,1	3,5 – 5,0
Flash point	°C	>110	17,5 – 19	>100
Ethanol cont.	% vol	- - -	20	
Water cont.	mg/kg	<300	10500-13000	
Cetane NR	- - -	>49	48	48
Energy cont.	MJ/kg	37,5	34,6	
Energy cont.	MJ/dm³	33,3	30,0	

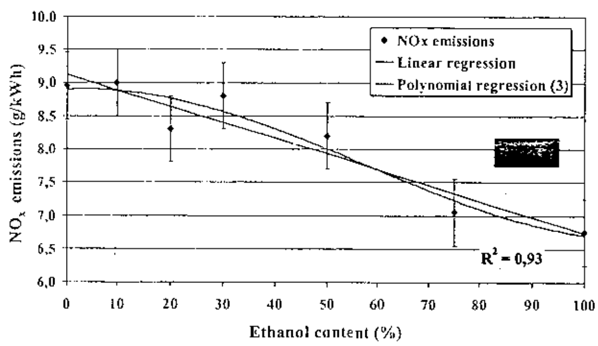
Cetane number vs. ethanol content



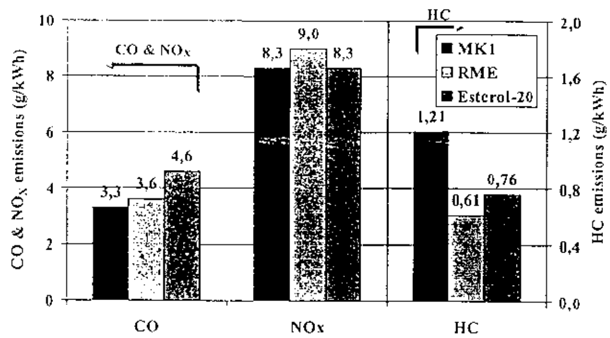
Material compatibility test



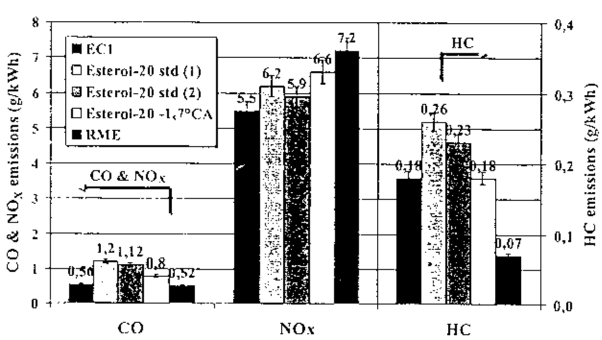
NO_X emissions



Regulated exhaust emissions
VAT test cycle



Regulated exhaust emissions
ECE R49 test cycle



Esterol project I
Field test

Esterol project I
Field test

Summary and conclusions Esterol I project

- Ordinary heavy duty CI engines can be fuelled by Esterol fuel blends with less than 30% ethanol without use of ignition improvers and without engine adaptations.
- NO_X and smoke emission levels from heavy duty CI engines on Esterol fuels decreases with increasing ethanol contents and become lower than those for diesel oil, EC1 quality, at 20% ethanol in RME.
- The smell of the exhaust gas emissions from vehicles without aftertreatment facilities was deemed unacceptable by operators. Catalytic aftertreatment of the exhausts must therefore be applied.

Esterol II
Project objectives

- To develop and demonstrate the feasibility of RME for use as ignition improver in neat ethanol fuels for CI engines.
- To define the optimum fuel formula for use in dedicated alcohol diesel engines for heavy duty operation.
- To demonstrate the environmental benignity of the optimum Esterol fuel formula for dedicated alcohol diesel engines.
- The acquisition of a neat fuel formulation with the capacity to enable lower fuel prices than the ethanol fuel so far used.
- To "decouple" the neat ethanol fuel formulas from the chemical industrial production strategies so as to make the neat ethanol fuel option less vulnerable to changing preferences.

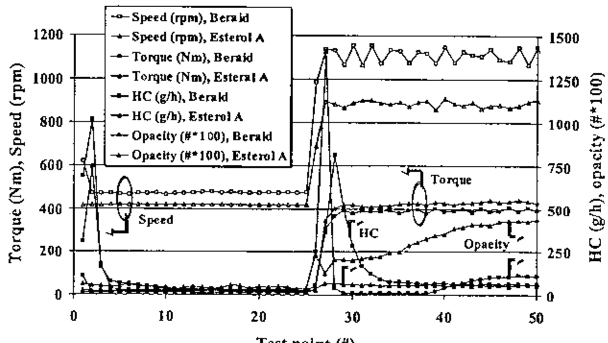
ESTEROL-II
Project work program

- Determination of Esterol fuel blend properties (Appearance, CFPP, viscosity, density).
- Determination of power output and cold start behaviour of various blends.
- Characterisation of regulated exhaust gas emissions (ECE R49 test cycle).
- Cylinder pressure measurements.
- Analysis of noice emissions.
- Selection of the optimum Esterol formula for fuelling dedicated ethanol diesel engines.
- Field test

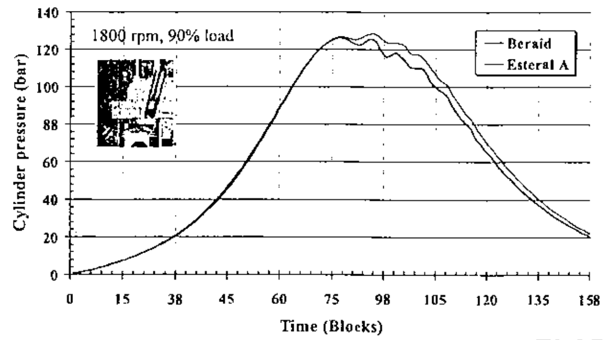
ESTEROL-II
Fuel properties

Fuel comp.	*Viscosity (mm^2/s)*	*CFPP (°C)*	*Cetane No.*
RME	4,439	-10	54,8
"Beraid"	1,405	<-40	n.d.
Esterol-80	1,282	-12	n.d.
Esterol-60	1,632	-10	n.d.

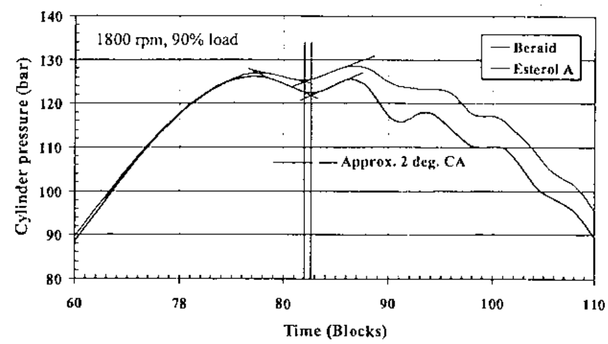
ESTEROL-II
Cold start properties, Esterol A vs. Beraid



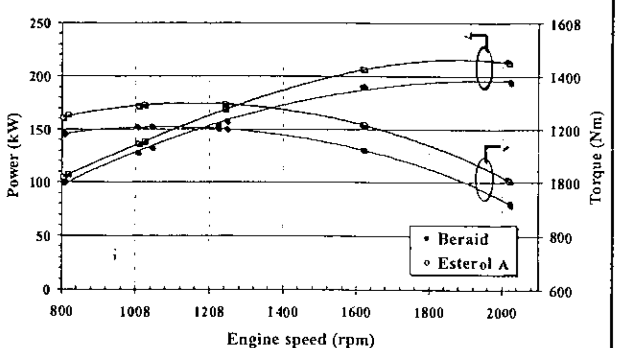
ESTEROL-II
Cylinder pressure measurement



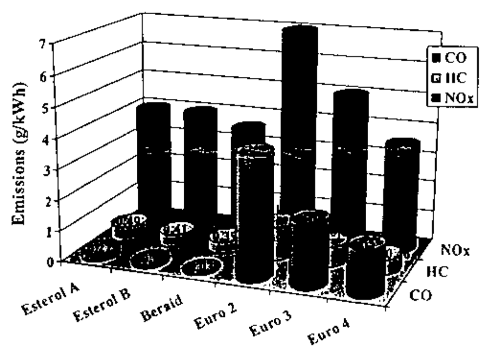
ESTEROL-II
Cylinder pressure measurement



ESTEROL-II
Power & torque vs. engine speed



ESTEROL-II
Exhaust gas emissions (ECE R49)



ESTEROL-II
Field test in the town of Örnsköldsvik

ESTEROL-~~II~~ I
Conclusions 1(2)

- Blends between RME and ethanol are better fuels for ordinary CI engines than neat RME and neat ethanol in respect of environmental properties and/or economy.
- Esterol-20 with 20% ethanol in RME can be used as fuel in ordinary CI engines without adding ignition improver substances.
- Esterol-X with X>20 requires ignition improver additives for acceptable drivability. NO_X emissions improve with increasing X.
- Esterol fuel use claims use of oxidative catalysts for alleviating unpleasant smell of the exhaust gas emissions.

ESTEROL-II

Conclusions 2(2)

- RME functions well as ignition improver for neat ethanol fuel for dedicated ethanol CI engines without loss of exhaust gas emission properties.
- Neat ethanol fuel with RME as ignition improver substance enables significantly cheaper ethanol fuel price.
- Neat ethanol fuel with RME as ignition improver substance makes the neat ethanol fuel option for fuelling CI engines less vulnerable for changing industrial product preferences.

Annex 7

Project time schedule.

Project Esterol II
Time schedule.