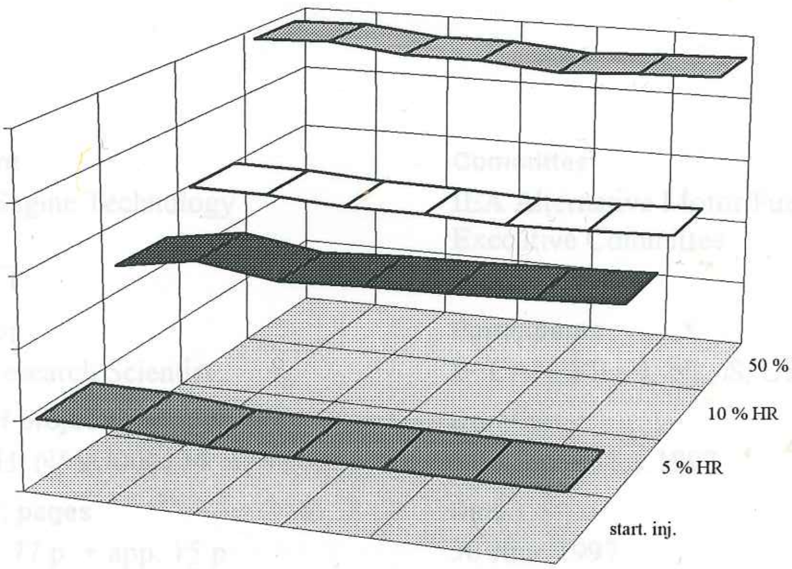
IEA Alternative Motor Fuels
Annex X
VTT report ENE24/21/97

CHARACTERIZATION OF NEW FUEL QUALITIES
Final report



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Abstract

The objective of this task was to evaluate the correlation between the results of standardised testing and of the real-life serviceability of new diesel fuel qualities. The following characteristics were studied: combustion properties, properties affecting exhaust emissions, low-temperature performance and diesel fuel lubricity.

The test fuel matrix comprised typical conventional hydrocarbon diesel fuels, low-emission hydrocarbon fuels, rapeseed and tall oil esters and ethanol-blended diesel fuels. The base fuels were blended with a cetane improver additive and some fuels also with a cold flow improver additive. Tests were carried out with VOLVO heavy-duty bus engine, VALMET medium heavy-duty engine and Audi 1.9 TDI vehicle.

Overall conclusions of this research work were as follows:

Traditional cetane number measurement:

∗ Describes well ignition delay of heavy-duty engine at low and medium loads, but is more suitable for hydrocarbon fuels than for alternative diesel fuels.
∗ Does not describe combustion process with advanced light-duty vehicles.
∗ Cetane reference fuels does not function as normal fuels in advanced engines.
∗ Overestimates the effect of cetane improvers, especially for biodiesels.
∗ Correlates with cold startability for some parameters.

Emissions:

∗ HC and CO are the highest for ethanol fuels, but may be reduced by adding RME. Cetane improver reduces HC and CO emissions in general.
∗ NO_x emissions are the lowest for ethanol fuels, but the effect will vary with engine technology.
∗ Particulate matter emissions are the lowest with ethanol fuels and Finnish low emission fuel. RME20 gives particulate emission benefit, if oxidation catalyst is used.
∗ The cetane improver reduces smoke opacity.

Lubricity, cold properties:

∗ Esters act as effective lubricity additives according to HFRR tests.
∗ Cold startability of RME blend can be improved with cold flow additives.
∗ Ignition of EtRE fuel improves significantly, when the ignition improver is used.

Preface

The objective of IEA/AMF Annex X "Characterisation of new fuel qualities" was to evaluate how the traditional test methods (cetane number and cold properties) developed for hydrocarbon fuels describe the real-life serviceability of new and alternative diesel fuels, esters and alcohol blends. The aim was not to develop new standards, but to demonstrate the shortcomings of current test methods in the characterisation of new fuel qualities. Combustion properties, properties affecting exhaust emissions, low-temperature operability and stability and diesel fuel lubricity were studied.

The tasks were carried out at the Technical Research Centre of Finland (VTT) in 1996 and the beginning of 1997. Some of the fuel analysis were carried out by the Finnish national oil company, Neste Oil.

Finland was the Operating Country for the task. In Finland, the Technology Development Centre (TEKES) and also VTT supported the task financially. Other participants in the task were Belgium, Canada, Japan, the Netherlands, Sweden and the United States.

We would like to thank Neste Oil, Forchem Oy, Raisio Oy and the Swedish Ethanol Foundation, who provided the test fuels for the task. Neste Oil also carried out special analyses on the test fuels (e.g. HFRR). Special acknowledgement goes to VAG company, who donated an Audi 1.9 TDI vehicle for the task. We also wish to thank Sisu Diesel Inc., who gave permission to carry out tests with their Valmet 612 engine.

This task was of basic research in nature, not of laboratory routine. All tasks had to be planned and conducted carefully. It would not have been possible to carry out the task without the skilled and enthusiastic staff of the Engine Technology Group of VTT Energy. We would like to thank all our collaborators responsible for the measurements. In particular, the cylinder pressure measurements required a lot of effort and development work.

Acknowledgement is given to Mr. Bernard James of Natural Resources Canada, who suggested this research topic to Mr Nils-Olof Nylund in 1993.

Espoo, Finland

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TECHNICAL RESEARCH CENTRE OF FINLAND

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PART TWO:
Emissions, combustion properties and startability at low temperatures

APPENDICES

Abbreviations

HC	total hydrocarbons in exhaust gases
CO	carbon monoxide in exhaust gases
NO_x	oxides of nitrogen in exhaust gases
ECE R49	Exhaust emission test procedure for heavy duty engines according to Regulation No. 49 of United Nations
FTP	Federal Test Procedure, exhaust emission test for light-duty vehicles, test procedure of US Environmental Protection Agency (EPA), presented in the Code of Federal Regulations, Title 40, Part 86
ASTM	American Society for Testing and Materials
HD	heavy-duty
MHD	medium heavy-duty
LD	light-duty
CFR	Cooperative Fuel Research, in this report single cylinder test engine for cetane number measurements according to ASTM D 613
DI	direct-injection
EGR	exhaust gas recirculation
FTIR	Fourier Transformation Infrared analyser
HR	heat release
IMEP	indicated mean effective pressure
TDC	top dead centre
BTDC	before top dead centre
rpm	engine speed in revolutions per minute
CN	cetane number
HFRR	High Frequency Reciprocating Wear Rig, test method for lubricity
CFPP	Cold Filter Plugging Point
SFPP	Simulated Filter Plugging Point
CEC	RF-03-A-84 reference fuel fulfils requirements presented in ECE R49 test procedure
ASTM2D	conventional diesel fuel in USA, fulfils requirements of ASTM 2 D specification
SCD	Finnish summer grade reformulated diesel fuel, so called CityDiesel
RME	rape seed methyl ester
TME	tall oil methyl ester
TOFA	tall oil fatty acids
EtOH	ethanol, in this report used as an abbreviation for emulsion of ethanol and diesel fuel
EtRE	abbreviation for emulsion containing diesel fuel, ethanol and RME
ci	cetane improver additive
cfi	cold flow improver additive

1 Introduction

The composition of liquid motor fuels is changing constantly. New fuel components are introduced either to reduce emissions or to broaden the basis of fuel supply. Oxygenated components, both alcohols and ethers are widely used as gasoline components. Biocomponents like vegetable oils and vegetable oil derivatives are discussed as diesel fuels or fuel components.

Many standardised tests for evaluating fuel properties have originally been designed for screening hydrocarbon products, often straight-run fuels. In the case of fuels blended with new components or treated with additives, the traditional test methods may give misleading results.

Ignition and combustion properties of motor fuels are evaluated by running engine tests with standardised test engines, for example CFR (Cooperative Fuel Research) engines. However, the technology of these engines is not representative of modern automotive engines. The properties of the reference fuels used to calibrate the test engines are also far away from those of both today's motor fuels and possible alternative fuels. It is, for example, already proven, that the cetane engine underestimates the ignition properties of alcohol treated with an ignition improver.

Standardised methods to evaluate cold properties of diesel fuels, i.e., cloud point, cold filter plugging point, etc., do not necessarily correlate well with the real cold performance of new or additive-treated fuels.

The idea of a task to characterize new fuel qualities for IEA Alternative Motor Fuels was first discussed at the 10th International Symposium on Alcohol Fuels in Colorado, USA, in November 1993. VTT presented a pre-proposal for discussion at the 17th IEA AMF EC meeting in Antwerp, Belgium, in February 1994. VTT presented the next proposal version at the 18th IEA AMF EC meeting in Toronto, Canada, in October 1994. The EC Committee accepted this proposal on condition that gasoline tasks are removed. The final modified proposal was presented at the 19th IEA AMF EC meeting in Stockholm, Sweden, in September 1995.

The objective of the new task is to evaluate the correlation between the results obtained by standardised testing and the real-life serviceability of new diesel fuel qualities. The aim is not to develop new standards, but to demonstrate the shortcomings of current test methods in the characterisation of new fuel qualities. Properties to be studied are:

* combustion properties
* properties affecting exhaust emissions
* low-temperature startability
* diesel fuel lubricity

2 Overview of the test programme

The test programme as well as description of the test facilities and methods are presented in detail at the beginning of each chapter. Table 1 gives an overview of the total test programme.

The number of tests carried out was higher than planned originally. This was due to an additional ethanol fuel proposed by the Swedish Ethanol Foundation. In addition, the number of steady-state test modes was higher than planned. Some laboratory research work, not included in the project plan, was carried out with ethanol fuels. The costs for the extension of the programme were funded by VTT. 4 000 USD is expected from Sweden for covering the costs of the additional ethanol fuel.

The results are presented according to the order of Table 1 in this report. The main purpose of the study was to find out, if the traditional cetane number measurement represents the real combustion properties also for alternative fuels. The conclusions are based on the results of combustion analyses and emission measurements with two heavy-duty engines and one light-duty vehicle. The summarised data processing and the conclusions are presented in chapter 7.

Table 1. Overview of the test program.

Studied parameter	Engine	No. of fuels	Test method	No. of tests
FUEL PROPERTIES				
Cetane number	CFR	14	ASTM D 613	17*
Cold properties		11	Cloud point, CFPP, SFPP	27
Other fuel analysis		7	density, viscosity, distillation, sulphur...*	31
LUBRICITY				
Lubricity		7	HFRR	7
COMBUSTION PROPERTIES AND EMISSIONS				
Combustion properties (cylinder pressure analysis), emissions and Bosch-smoke	VOLVO THD 103 KB, HD bus engine	14	ECE R49, 13 modes	28**
Combustion properties (cylinder pressure analysis), emissions	Audi 1.9 TDI vehicle	14	5 steady-state loads	18**
Combustion properties (cylinder pressure analysis), emissions	HD engine, VALMET 612	14	4 loads	14
COLD TESTS				
Real cold startablility	MHD engine, VALMET 620	4	in-house method	10
Combustion properties (cylinder pressure analysis), emissions and opacity	HD engine, VALMET 612	6	4 loads	6
FTP emissions at +16 and -6 °C	Audi 1.9 TDI vehicle	6	FTP, two temperatures (+16 and -6 °C)	12
SUM				**170**

* includes also in vitro stability tests of cetane improvers for ethanol fuels.

** includes replicate tests and different modes

3 Test fuels

3.1 Test fuel matrix

The base diesel fuel matrix comprised CEC reference fuel, conventional diesel fuel from North America (ASTM 2D grade), Finnish low-emission diesel fuel (no sulphur, low aromatics), CEC diesel fuel blended with rapeseed methyl ester and tall oil methyl ester. Also two ethanol blends were added to the matrix. The ethanol-blended fuels were emulsions blended with Swedish Environmental Class 1 diesel fuel, one with ethanol only and one with ethanol and rapeseed ester (the latter proposed by Sweden). Two cetane reference fuels were tested with the light-duty vehicle, one with a low and the other with a high cetane number.

Some of the base test fuels were blended with a cetane improver additive to find out the effect of additive. The effect of a cold flow improver package was studied as well.

CEC reference fuel (CEC-RF-03-A-84) was provided by Neste Oil (Finnish national oil company). The CEC reference fuel was blended from ordinary refinery streams to fulfil the RF-03-A-84 requirements. Sulphur content (0.12 wt%) was acceptable for CEC fuel, but it must be noticed that typical fuel of the market today contains below 0.05 wt% sulfur.

A typical diesel fuel, corresponding to the North American **ASTM 2D** standard requirements, was purchased from USA, Houston. The fuel was a commercial grade.

A Finnish summer-grade low emission fuel, **SCD**, was chosen to represent Scandinavian low-emission diesel fuels. The national requirements on low-emission diesel include, e.g., limits for cetane number (min. 53), aromatics (max. 20 vol%) and sulphur (max. 0.005 wt%). In the Nordic countries, there are several widely used low-emission diesel fuel qualities available. The Finnish summer grade low-emission diesel fuel was chosen, as it gives about the same emission benefits (especially when the unregulated emissions are concerned), but does not lead to increased fuel consumption or power loss as the lightest fuel qualities available on the market.

The rapeseed methyl ester fuel (RME20) was blended from the CEC reference fuel and 20 vol% of rapeseed methyl ester provided by the Finnish Raisio Oy company.

The original idea with **tall oil** products within this research work was to study a Canadian high cetane (CN90) hydrated tall oil component from ARBOKEM. Unfortunately ARBOKEM was not able to provide the hydrated tall oil component for the project, and the hydrated tall oil was replaced by another tall oil product, tall oil methyl ester. A Finnish company, Forchem Oy (nowadays part of Arizona Chemical), provided the tall oil methyl ester.

Tall-oil is a by-product of the pulping industry. Tall-oil methyl ester (TME) is produced from tall oil fatty acids (TOFA). The Finnish production capacity of TOFA is about 50 000 tonnes per year, i.e., about 3.5% of the diesel fuel consumption in Finland. The most important tall oil producer in the world is Canada.

The composition and properties of TME are similar to those of RME. The advantage of TME over RME is the different production process (see Figure 1), where the by-product is water and not glycerol, which might be more harmful in respect of the operability of the engine.

Production of TME:

RC(O)OH	+ CH_3OH	--->	$RC(O)OCH_3$ +	H_2O
TOFA	*methanol*		*TME*	*water*

Production of RME:

CH2O(O)R				CH2OH
I				I
CHO(O)R	+ 3 CH_3OH	--->	3 $RC(O)OCH_3$ +	CHOH
I				I
CH2O(O)R				CH2OH
triglyceride	*methanol*		*RME*	*glycerol*

Figure 1. Production of TME and RME.

Sweden is the leader in the research of **ethanol** as a transportation fuel. For example, all the buses in central Stockholm, the capital of Sweden, are running on neat ethanol. During the past few years, ethanol research in Sweden has also covered ethanol-blended diesel fuels. Ethanol is a polar compound, which cannot be blended with nonpolar hydrocarbons without emulsifier. Hence, the Swedish ethanol-diesel blends contain less than 1 vol% of emulsifier, which is purchased from Australia. Ethanol emulsion containing Environmental class 1 diesel fuel, 15 vol% ethanol and less than 1 vol% emulsifier is called "Etamix 15" **(EtOH15).** Several studies have been carried out on this fuel in Sweden, including laboratory tests, engine and emission tests, and a field test program is going on. Perhaps the most important problem with the Etamix fuel is the stability: the ethanol and the diesel fuel tend to separate phases after a three-month storage.

EtOH15 fuel was provided for this project by the Swedish Ethanol Foundation. During the discussions, representatives of Swedish Ethanol Foundation informed that cetane improver additives are not soluble in the EtOH15 emulsion. However, the conclusion was based only on tests with a Swedish cetane improver specially developed for the neat ethanol fuels. As the Etamix fuel contains only 15 vol% of ethanol, VTT decided to start laboratory tests with a cetane improver (2-ethyl nitrate based) developed for conventional hydrocarbon diesel fuels. As a result, it turned out that conventional cetane improvers can be used in ethanol emulsions and at least some cetane number benefit is achieved. The heavy-duty tests were carried out before the laboratory tests were completed. Thus the ethanol fuels with a cetane improver additive were not included in the heavy-duty tests with the VOLVO engine.

The Swedish Ethanol Foundation suggested that an additional ethanol fuel containing also rapeseed methyl ester should be included to the test fuel matrix. The blend of Swedish environmental class 1 diesel fuel, containing about 10% of ethanol, 4.3% RME and emulsifier additive, **EtRE,** was included in the project after acceptance of the partners in spring 1996.

Reference fuels of the ASTM D 613 cetane number test procedure, with cetane numbers 43 and 60 (**CNref60** and **CNref43**) were tested with the light-duty vehicle. Cetane reference fuels are mixtures of n-cetane (n-hexadecane, CN 100) and high branched paraffin heptamethylnonane (CN 15)[1]. Thus the distillation ranges of these fuels are very narrow: only about 245 - 287 °C. The ASTM reference fuels are so expensive, that the tests with a heavy-duty engine with high fuel consumption would not have been possible within this project.

Summary and abbreviations of the tests fuels are as follows:

Base fuels:

CEC:	CEC reference fuel
ASTM2D:	ASTM 2-D diesel fuel from North America
SCD	Scandinavian low-emission diesel fuel
RME20	CEC diesel fuel containing 20% rape seed methyl ester
TME20	CEC diesel fuel containing 20% tall oil methyl ester
EtOH15	diesel fuel emulsion containing 15% ethanol
EtRE	diesel fuel emulsion containing 10% ethanol and 4.3% RME

In addition, cetane reference fuels CNref60 an CNref43 were tested with an LD vehicle.

Base fuels blended with cetane improver additive:

CEC+ci:	CEC containing 1 000 ppm cetane improver
ASTM2D+ci:	ASTM 2D containing 1 000 ppm cetane improver
SCD+ci	SCD containing 1 000 ppm cetane improver
RME20+ci	RME20 containing 1 000 ppm cetane improver
TME20+ci	TME20 containing 1 000 ppm cetane improver
EtOH15+ci*	EtOH15 containing 1000 ppm cetane improver
EtRE+ci*	EtRE containing 1 000 ppm cetane improver

** For the reasons given above these fuels were not tested with all test engines.*

Base fuels blended with cold flow improver:

CEC+cfi:	CEC containing 500 ppm cold flow improver
ASTM2D+cfi:	ASTM 2D containing 500 ppm cold flow improver
SCD+cfi:	SCD containing 500 ppm cold flow improver
RME20+cfi:	RME20 containing 500 ppm cold flow improver
TME20+cfi:	TME20 containing 500 ppm cold flow improver

3.2 Fuel properties

The properties of the test fuels are presented in Appendix 1. The most important fuel properties are presented also in Table 2.

The lowest density of the test fuels was measured for the EtOH15 fuel, the heaviest fuel was ASTM2D. The variation of density was, however, not extremely wide. The viscosities of the test fuels were more or less of the same level.

The natural cetane numbers of the test fuels ranged from 45 to 55, (ethanol fuels excluded). The cetane number of the ASTM 2D fuel was lowest of the hydrocarbon fuels (45, ASTM 2D requirement min. 40). The cetane numbers of the other fuels were close to 50. The SCD fuel had the highest cetane value. Response to the cetane improver additive was highest for ester-containing fuels: cetane numbers increased by more than 10 units. The lowest response to the cetane improver was found for the ASTM2D fuel: improvement only by 2 units. The cetane numbers with and without the additive are shown in *figure 2*.

The cetane number measurement with the CFR engine was not easy to carry out for ethanol fuels. The engine was not running smoothly and the readings varied continuously. In addition, the results from the first ethanol batch differed from the second batch. The first batch of ethanol fuels was used for the heavy-duty tests. The light-duty tests were carried out more than three months after the arrival of the first batch. The stability of the ethanol fuels is only three months, and hence the second batch of ethanol fuels was used for the light-duty tests. The cetane number of the first batch of EtOH15 was some 42. For the second batch the cetane number was very difficult to analyse, and the result was as low as 34. This might be due to the timetable of cetane measurements for the second batch: the fuels had to be stored during cold wintertime, which might accelerate the phase separation. On the other hand, both fuels of the second batch with cetane improvers, EtOH15+ci and EtRE+ci, gave cetane numbers (about 49) comparable to the first batch, even though they were stored similarly to the fuels without a cetane improver additive.

Sulphur content of CEC, RME20 and TME20 fuels were high compared with present commercial diesel fuels, which have to be taken into account when the particulate matter emissions are considered.

The cloud points could not be analysed for the ethanol emulsions because of their white colour. The cloud points of the other fuels were from -5 to -7 °C except for ASTM 2D, which had a low cloud point of -14 °C.

Traditionally CFPP (cold flow plugging point) is considered as the most important cold property of diesel fuel representing cold operability. The CFPP values without the cold flow additive ranged from -9 to -14 °C, ethanol fuels excluded. The CFPP results of ethanol fuels were lower than -39 °C due to very light blending components, Swedish environmental class 1 diesel and ethanol. Hence, there was no reason to add cold flow additives to the ethanol fuels.

The response of the fuels to the cold flow additive was highest with the SCD fuel. The CFPP additive used in this project was typical chemistry and available from major additive suppliers. The effect of cold flow additive is known to depend on the composition of the fuel. Thus it was logical that the response of this additive used in Finland was highest with the Finnish diesel fuel.

The CFPP testing method has been criticised in some cases for its high response to the cold flow additives, giving results which do not reflect real cold operability. The SFPP testing method is a new test, which is claimed to represent better the real cold operability than CFPP. The basic equipment used for SFPP analysis is the same as used for CFPP. The major differences are the filter pore size and slower temperature changes.

The results indicate that the SFPP values differed considerably from the CFPP results, especially when the additive was used. The SFPP results without an additive ranged from -5 to -7 °C and with an additive from -12 to -15 °C, whereas the respective CFPP results ranged without an additive from -9 to -10 °C and with an additive from -14 to -26 °C.

Table 2. The most important fuel properties. All analysed fuel properties are presented in Appendix 1.

	CEC	**ASTM 2D**	**SCD**	**RME20**	**TME20**	**EtOH15**	**EtRE**
Density, 15 °C, kg/dm^3	0.841	0.847	0.826	0.850	0.851	0.817	0.820
Viscosity, 40 °C, mm2/s	3.0	2.4	2.7	3.3	3.2	3.1	2.4
Sulphur, wt%	0.12	0.038	<0.002	0.081	0.081	<0.002	<0.002
Cetane number w/o ci	53.0	45.0	54.8	48.4	47.0	42.6/ 34.2	48.8/ 41.2
Cetane number with ci	57.9	47.4	60.7	60.4	62.4	45.5/49.8	-/48.5
Cloud point, °C	-5	-14	-8	-5	-7	**	**
CFPP w/o cfi, °C	-10	-14	-9	-9	-10	-39	<-39
CFPP with cfi, °C	-14		-26	-21	-24		
SFPP w/o cfi, °C	-6		-7	-5	-6		
SFPP with cfi, °C	-12		-12	-12	-15		
HFRR, 60 °C, µm	385	391	306	172	282	226	182

* The CFR engine was not running correctly with ethanol fuels. The two values were analysed for different production batches. Ethanol emulsions are stabile only for three month, and hence, the first batch was used for VOLVO heavy-duty measurements and the second batch for the other tests.

** Test method is not suitable for ethanol fuels.

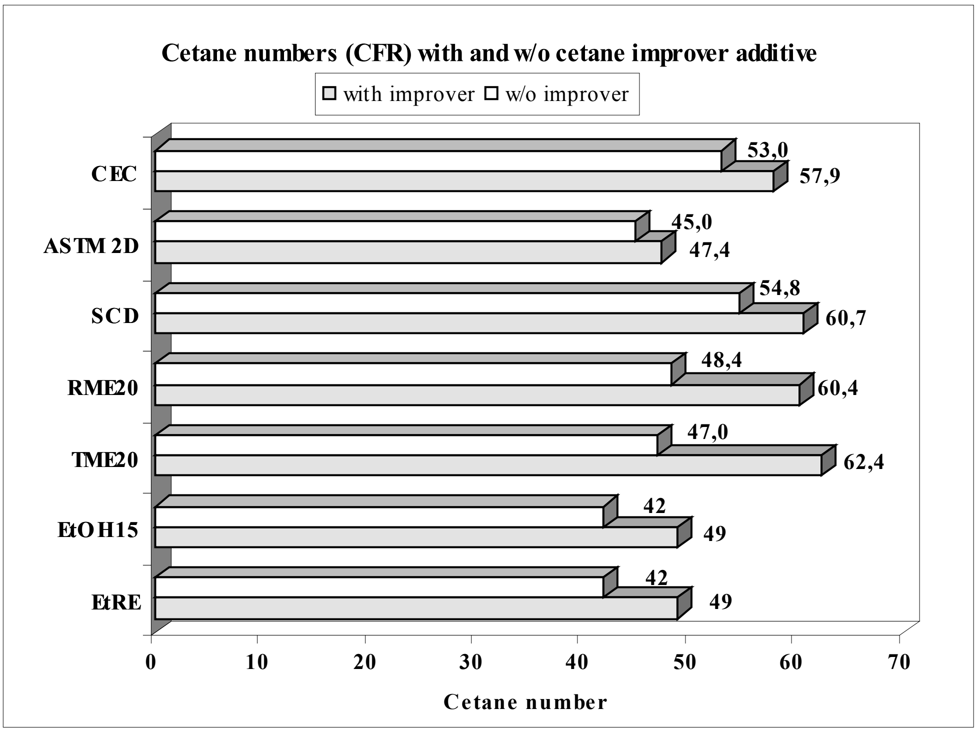


Figure 2. Cetane numbers of the test fuels with and without a cetane improver. The cetane results of the ethanol fuels varied a lot, and the results presented are selected values.

3.3 Lubricity

Lubricity of the test fuels was measured with the HFRR method (High Frequency Reciprocating Rig) at 60 °C. The HFRR method has tentatively been accepted by CEC as a standard method for lubricity, even though it has been widely criticised. There is a need for a reliable laboratory method for lubricity, because the "real world" method, running real injection pumps for long periods, is extremely expensive and difficult to perform.

The HFRR method is claimed to give benefit to certain types of lubricity additives and undervalue the others, even though additives have been proved to be as good as the others with the reliable pump test. The method is based on a wear test with hardened steel balls.

The test is conducted on a test rig where a loaded 6 mm bearing ball is moved with a reciprocating motion over a static steel plate. The contacts are in flooded lubrication. The metallurgies, temperature, load frequency, stroke lenght, and ambient conditions are specified, and the size of the wear scar produced on the ball bearing is used as a measure of the fuel lubricity. The HFRR lubricity results describe the wear scar diameter of testing balls (µm): the lower the result, the better the lubricity.

The lubricitities of all test fuels were acceptable (see *table 2*). The CEC limit value for lubricity with the HFRR test method is 450 µm at 60 °C.

The best lubricity results were achieved with the ethanol and ester blended fuels. It was interesting to compare the CEC fuel and CEC fuel blended with esters. These fuels do not contain any lubricity additives and may be compared with each other. The wear results with ester blended CEC fuels were significantly better than without esters. It can be concluded that the esters act as effective lubricity improvers.

Lubricity additives are used in Scandinavian low emission and winter grade diesel fuels. Both SCD and Swedish Environmental Class 1 fuel, which was used for blending ethanol emulsions, contain lubricity additive. Thus SCD and ethanol fuels gave acceptable results as expected. The lubricity results of ethanol emulsions were good, very near to the values reported in literature[2]. HFRR results indicate that ethanol emulsion would not harm the lubricity performance of diesel fuels, but only the pump test is reliable enough to make conclusions. One observation of importance is also the lubricity result with RME containing ethanol emulsion fuel superior to the ethanol blend without RME. This gives more evidence for the effect of esters as lubricants mentioned earlier.

Good lubricity results were obtained also for the CEC and ASTM 2D fuels. ASTM 2D was of commercial grade and most probably did not contain any lubricity additive. CEC did neither contain any lubricity additive. It is hence understandable that the wear values of these fuels were higher than those of the other fuels, but anyway acceptable (below 400 µm).

PART ONE:

Emissions and combustion properties at normal temperature

4 Heavy-duty tests, VOLVO THD 103 KB

4.1 Heavy-duty engine, VOLVO THD 103 KB

The greater part of the heavy-duty engine tests for emissions and combustion properties were carried out with a VOLVO THD 103 KB bus engine. Even though the engine is designed for Euro 1 emission levels, it meets the Euro 2 limits for regulated gaseous exhaust emissions. Only particulate matter emission exceeds slightly the Euro 2 limit. If an oxidation catalyst or a particulate filter is used, the Euro 2 requirements are well met. The particulate emission without the oxidation catalyst is about 0.15 - 0.20 g/kWh, the Euro 2 limit being 0.15 g/kWh. The VOLVO engine was run at normal room temperature.

The specifications of the engine are as follows:

Identification	*VOLVO THD 103 KB, horizontal bus engine, 1992* *turbo-charged* *direct-injection* *in-line pump (semi-electronic control)* *inter-cooled (water/air)*
Displacement	*9.6 litre*
Cylinders	*6, in-line*
Power output	*210 kW / 2000 rpm, 1200 Nm / 1300 rpm*
Compression ratio	*19:1*

4.2 Test procedures and facilities

ECE R49 test procedure

The heavy-duty tests were carried out according to the ECE R49 test procedure, which includes 13 load modes with various torque and speed levels (*Figure 3*).

The injection pump of a diesel engine operates on a volumetric base. E.g., a low-density fuel with a low aromatics content produces less power than a high-density, highly aromatic fuel, and this affects the emission level. When the fuels are compared with each other, it is reasonable to use the same power output, something which is often called the "constant torque" method.

The ethanol-containing fuel, EtOH15, being the lightest test fuel, was selected as the “constant torque” base fuel. The torque values achieved with EtOH15 were used for the other fuels. The maximum power with EtOH15 was 180 kW/2 000 rpm and maximum torque 1 060 Nm/1 300 rpm.

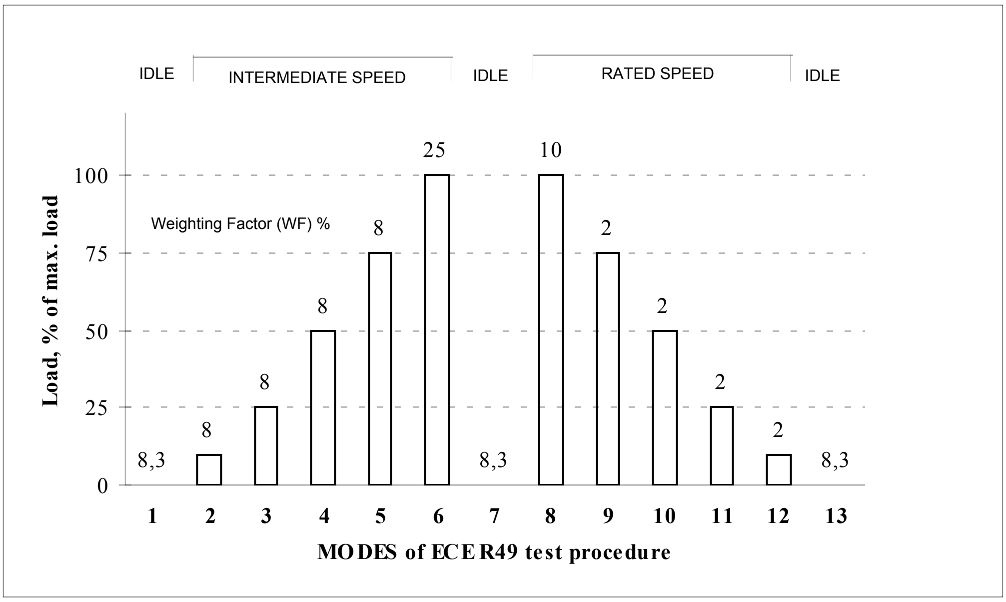


Figure 3. Test sequence of the ECE R49 13-mode test cycle

Basic test facilities

The general lay-out of the test arrangements for heavy-duty engine testing at VTT is shown in *Figure 4*. A hydraulic engine dynamometer by Zöllner and a "PUMA Test Assistant" control system by AVL were used for running and controlling the test engine.

Figure 4. General lay-out of heavy-duty test arrangements.

Measurement of combustion properties

The cylinder pressure analysis included measurements of the cylinder pressure trace, needle lift trace, injection pressure trace and crank position. The calculated parameters were indicated mean effective pressure, start and duration of injection, ignition delay and heat release parameters.

The cylinder pressure analysis was carried out with a combustion analyser from AVL, the AVL 647 Indiskop, which is basically a fast multichannel digital oscilloscope. Using built-in calculation algorithms, the Indiskop calculates, among other things, signals as a function of crank angle and heat release during different phases of combustion.

The following measurement system was used to measure combustion properties:

- Cylinder pressure transducer (Kistler)
- Needle lift transducer (Bosch)
- Injection pressure transducer (AVL)
- Charge amplifier, cylinder and injection pressure (Kistler)
- Crank angle encoder (AVL)
- Combustion analyser (AVL 647 Indiskop)

The measurements were done on cylinder number 1 (timing gear end). The TDC was determined from the maximum pressure of the non-firing cylinder taking into account the thermodynamic loss angle.

The combustion properties were measured during each mode of ECE R49 test procedure, except for idle modes.

The parameters measured and calculated were as follows:

1. intake manifold pressure, mbar
2. start of injection, °CA (needle lift sensor)
3. end of injection, °CA (75 or 100 bar fuel line pressure)
4. cylinder pressure peak value, BAR
5. angle of peak, °CA
6. maximum pressure gradient, BAR/°CA
7. angle of maximum pressure gradient, °CA
8. IMEP, indicated mean effective pressure, BAR
9. start of combustion, °CA
10. 5 % heat release, °CA
11. 10 % heat release, °CA
12. 50 % heat release, °CA
13. 90 % heat release, °CA
14. ignition delay, °CA (start of injection - start of combustion)
15. location of maximum heat release intensity, °CA
16. centre of gravity of combustion, °CA
17. maximum temperature, °CA

For diesel engines, start of combustion is normally detected by the Indiskop from the instantaneous heat release curve. However, with the late injection and combustion of the VOLVO engine, the built-in algorithm does not work properly. Therefore start of combustion in the case of the VOLVO engine (and also for the AUDI engine described later) was defined as the crank position corresponding to 5% cumulative heat release. This detection method is normally used for gasoline engines.

It should be noted that best accuracy of the heat release calculation is achieved on full torque. On low loads the spread in results increases, especially in the case of 90% heat release.

Regulated emissions

Regulated gaseous pollutants (CO, HC and NO_x) were measured continuously with an "AMA 2000" analyser system supplied by Pierburg GmbH. Particulates were collected using an AVL Mini Dilution Tunnel 474 (MDT) and particulate filters with 70 mm diameter.

Formaldehyde, FTIR-analysis

A fast on-line FTIR-instrument was used to measure formaldehyde from raw exhaust gas[3,4]. More than 20 components can be calibrated to VTT's SESAM system, which makes it possible to monitor the concentrations of, e.g., formaldehyde at one-second intervals.

In these measurements, concentrations of individual components were analysed during the ECE R49 test procedure at one-second intervals. The average values of the last 30 seconds of each mode were used for screening emission concentrations.

Bosch smoke

Bosch smoke was measured with an AVL Smokemeter during each mode of ECE R49 test procedure.

4.3 Test programme

The tests with the VOLVO THD 103 KB engine were carried out with the base fuels and with cetane improver added to the base fuels. The reference fuel was tested before and after the test period to verify the system stability. The summary of the test programme is presented in Table 3.

The ethanol containing fuels were tested only without the cetane improver. This because the information at hand when the tests started said that cetane improvers are not soluble with ethanol fuels.

Table 3. Test programme of HD tests with VOLVO THD 103 KB engine.

Fuel	No. of ECE R49 tests	Cylinder pressure analysis	Regulated emissions, formaldehyde*	Bosch Smoke
CEC: *CEC+ci:*	2 2	2 * 13 modes 2 * 13 modes	2 * 13 modes 2 * 13 modes	2 * 13 modes 2 * 13 modes
ASTM2D: *ASTM2D+ci:*	1 1	13 modes 13 modes	13 modes 13 modes	13 modes 13 modes
SCD *SCD+ci*	3 1	3 * 13 modes 13 modes	3 * 13 modes 13 modes	3 * 13 modes 13 modes
RME20 *RME20+ci*	1 1	13 modes 13 modes	13 modes 13 modes	13 modes 13 modes
TME20 *TME20+ci*	1 1	13 modes 13 modes	13 modes 13 modes	13 modes 13 modes
EtOH15	2	2 * 13 modes	2 * 13 modes	2 * 13 modes
EtRE	2	2 * 13 modes	2 * 13 modes	2 * 13 modes
SUM	*18*	*234*		

* *formaldehyde analysed only for ASTM2D and ETRE fuels.*

4.4 Stability of measuring system

The standard deviation of the regulated pollutants of the VOLVO THD 103 KB engine in the ECE R49 test are typically lower than 5 % of the absolute value of each gaseous pollutant and lower than 10 % for particulate matter. This was also the case in these measurements. Average standard deviation for gaseous pollutants were typically lower than 2 % and for particulates lower than 4 %.

The reference fuel was tested three times during the test period (see Figure 5). The variations of HC, CO, NO_x and particulate emissions were within the standard deviation of the test method during the test period.

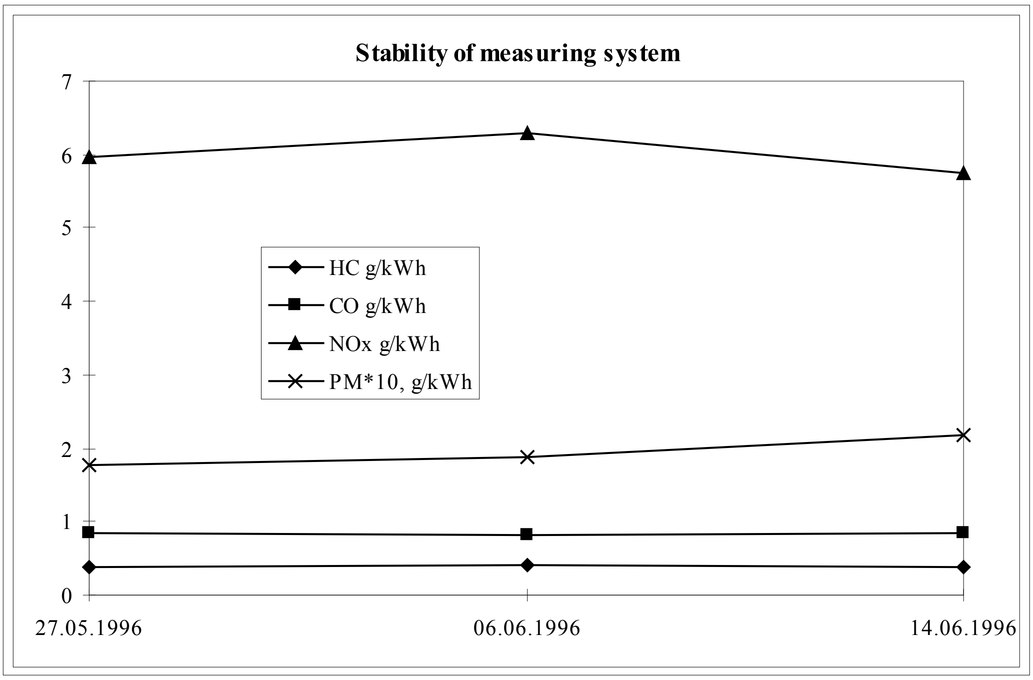


Figure 5. Stability of measuring system, VOLVO THD 103 KB with ECE R49 test procedure.

The standard deviations of the combustion parameters were better than expected (see appendix 4). For example variation in centre of gravity of combustion were mostly under 5 %.

4.5 Regulated emissions, Bosch smoke and FTIR analysis

The numeric results of the regulated emissions and Bosch smoke measurements are presented in Appendices 2 and 3.

Regulated emissions

The results for regulated emissions with the heavy-duty VOLVO bus engine without oxidation catalyst are shown in *figures 6* and *8*.

The lowest HC emissions were obtained for CEC, SCD, and for fuels containing bioesters. The ASTM 2D fuel and the ethanol blends resulted in higher HC values than the other fuels. EtOH15 gave about 40% higher HC emission than CEC fuel. The difference in HC emissions on ethanol blends and CEC fuel was seen only on low loads, especially during mode 12 (*figure 7*), where ignition properties of the fuel are known to be critical. Adding RME to the ethanol blend decreased HC emission significantly. HC emissions for the EtRE fuel were only about 10% higher than for the CEC fuel, compared to some 40% for EtOH15.

The CO emissions for different fuels followed similar patterns as the HC emissions.

The fuel had limited effects on the NO_x emissions, with the exception of the ethanol blends, which gave some 35% lower NO_x emissions in the ECE R49 test than the CEC fuel. As it is seen from *figure 6*, the ethanol blends gave lower NO_x emissions on medium and high loads (modes 4 - 10). At low load modes 2, 3, 11 and 12 the NO_x emissions were even higher than for the reference fuel. NO_x is one of the most important issues for diesel-fuelled vehicles at the moment.

The CEC fuel gave higher particulate emissions than the other hydrocarbon fuels, most probably due to higher sulphur level. The ethanol blends gave the lowest particulate emissions: close to only one half of those of the CEC fuel. The Scandinavian low-emission fuel, SCD, gave the lowest results after ethanol fuels: about 12% reduction compared with the CEC fuel.

The highest particulate emission was obtained with the TME containing fuel. Sulphur level of TME20 and RME20 fuels were high, which effect on total particulates. It is also known from previous studies that bioesters tend to increase particulate matter when no oxidation catalyst is used. This is due to a high amount of soluble organic matter in particulates. An oxidation catalyst reduces effectively the amount of soluble organic matter, which results in reduced particulate emissions with ester fuels. However, no increase in particulates for the RME fuel was observed.

Bosch smoke

Bosch smoke (black smoke) results on low load mode 2 and high load mode 8 are shown in *figure 9*. The Bosch smoke values were low for all fuels. Thus the differences were not really significant. The lowest Bosch smoke values were observed for the ethanol blends at all loads. The ASTM 2D fuel gave also somewhat lower result than the other fuels.

One interesting observation was that at low loads the Bosch smoke increased with increasing cetane number. It might be possible that the combustion process is not complete with low-cetane fuels, and this leads to a shift from “dry” black particulates to “wet” particulates and reduced black smoke.

Effect of cetane improver on regulated emissions and Bosch smoke

The cetane improver decreased CO emissions of all fuels (*figure 8*). The highest reductions were about 15%. Similar reductions in HC emissions were observed for ester blended fuels. The changes in NO_x emissions with the cetane improver additive were not significant. The only significant reduction in particulate emission using the cetane improver additive was observed for the SCD fuel. The particulate emission increased when cetane improver was added to the TME20 fuel. The changes in particulate emissions for the other fuels blended with the cetane improver were insignificant.

A peculiar effect of the cetane improver was found in Bosch smoke measurements. At low loads Bosch smoke increased when the cetane improver was added to the fuel. The same effect was not observed at high loads. This effect might be due to the same factor as discussed previously. With low cetane fuels the combustion process at low loads might be less complete and thus produce “wet” particulates. Wet particulates contain more hydrocarbons and less black carbon, which leads to lower black smoke (Bosch smoke).

FTIR analysis

FTIR analysis was carried out for the ASTM+ci and EtRE fuels. In the exhaust of the VOLVO engine the concentrations of most compounds calibrated into the FTIR equipment were below the detection limit .

Formaldehyde concentrations exceeded the detection limit (4 ppm) at all load points of ECE R49 test. It was observed that formaldehyde concentrations were higher for the ETRE fuel than for the hydrocarbon fuel at all loads, especially at mode 12 (rated speed, 10% load).

NO_2 concentrations were higher for EtRE fuel than for ASTM2D fuel at all loads.

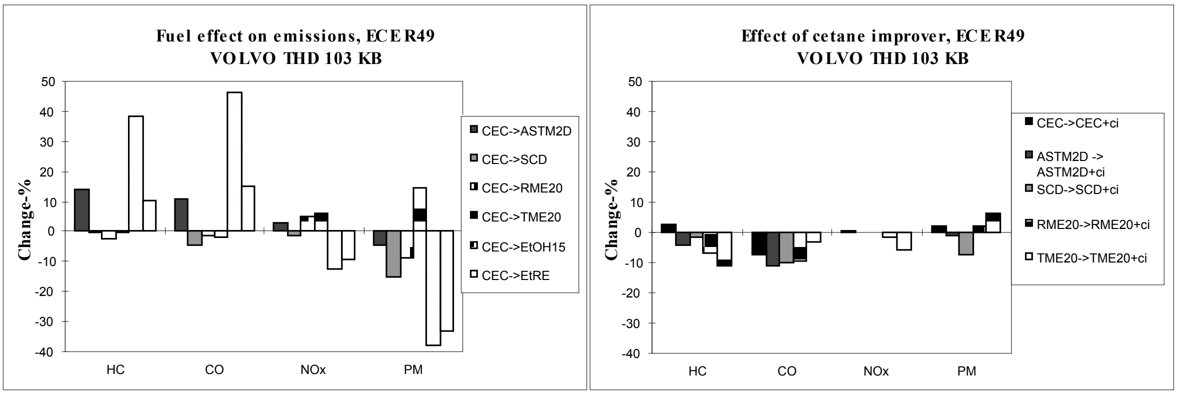


Figure 6. Changes in emissions with VOLVO THD 103 KB according to ECE R49 test procedure. Changes of gaseous emissions lower than 5% and particulates lower than 10% are insignificant.

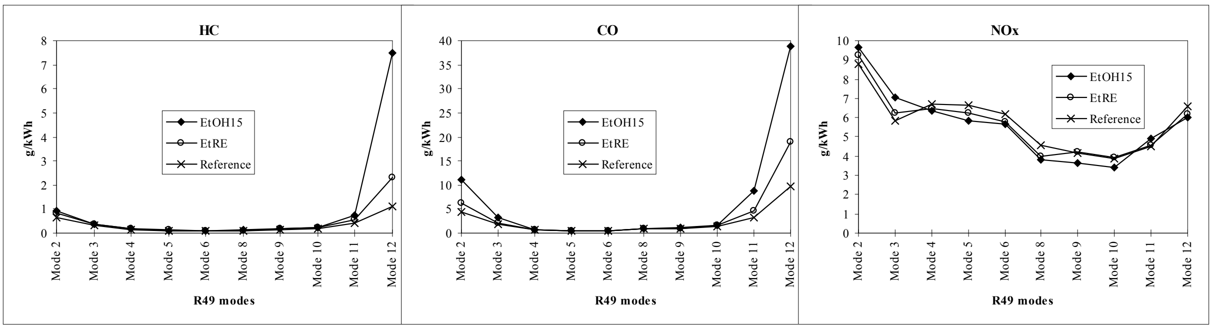


Figure 7. Comparison of the ethanol blends and the reference fuel in different modes of ECE R49. Modes 5, 6, 8, and 9 are high-loads (75 - 100% of maximum) and the others low loads (10 - 50% of maximum load).

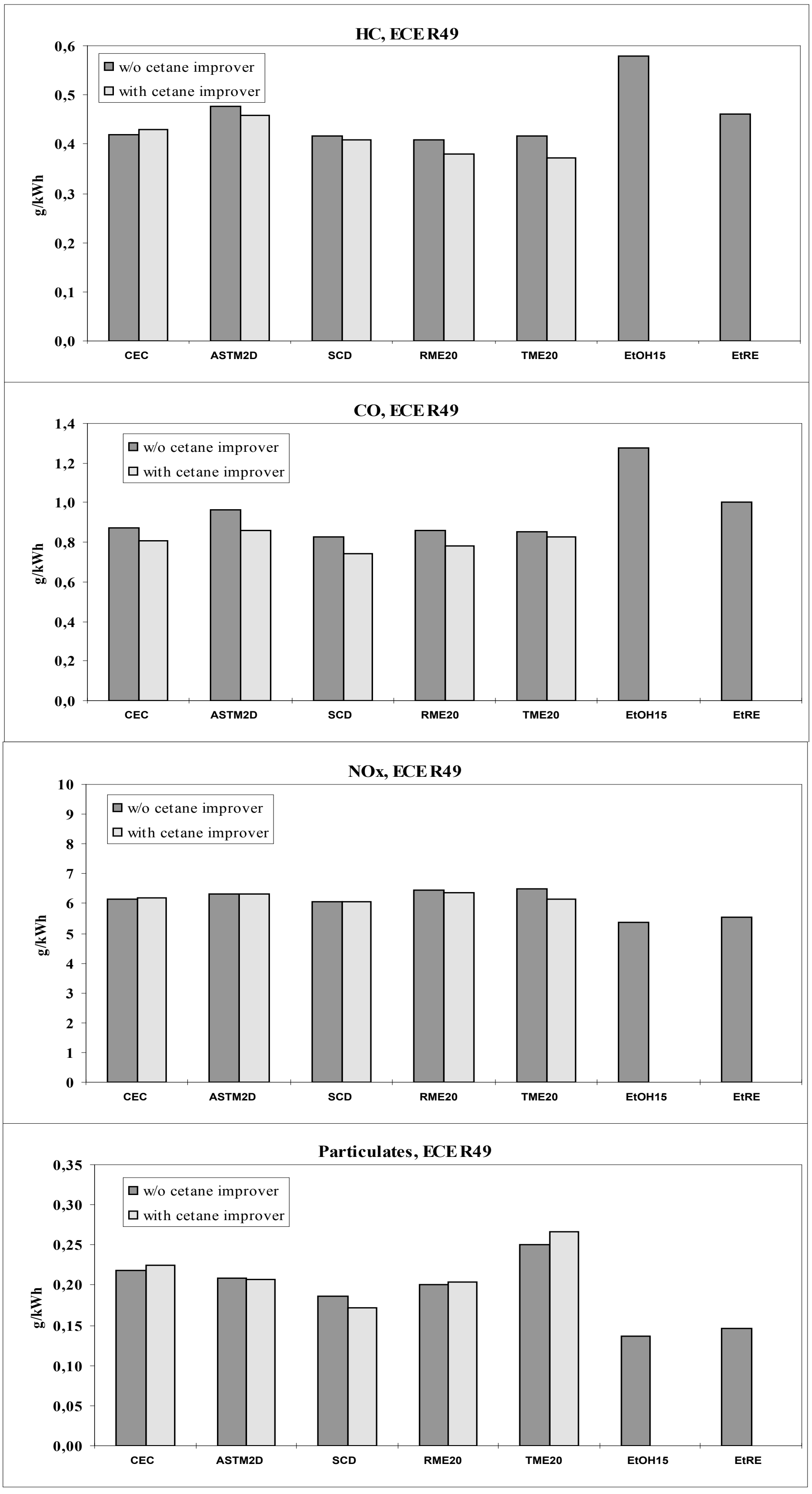
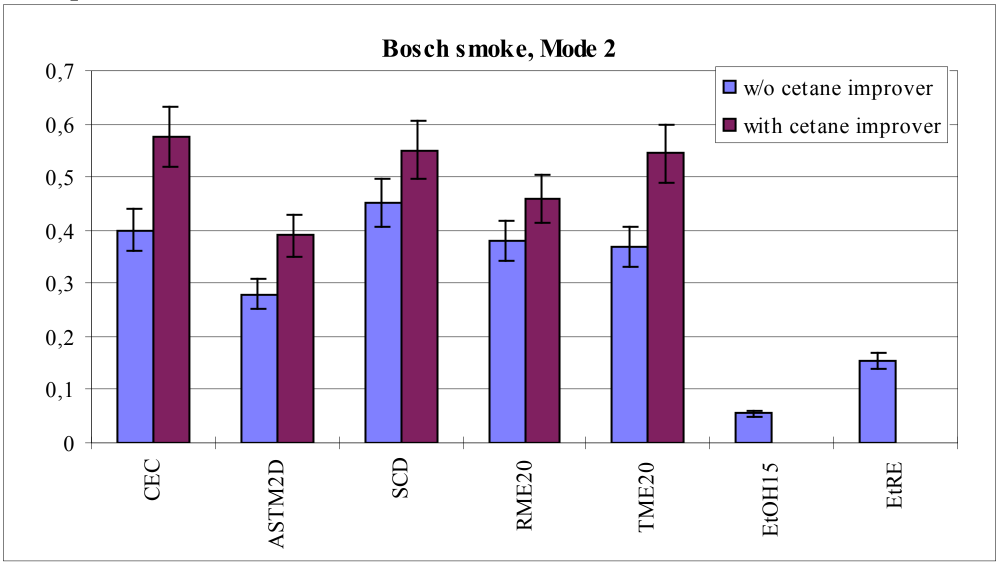


Figure 8. The regulated emissions of the heavy-duty VOLVO engine according to the ECE R49 test procedure.



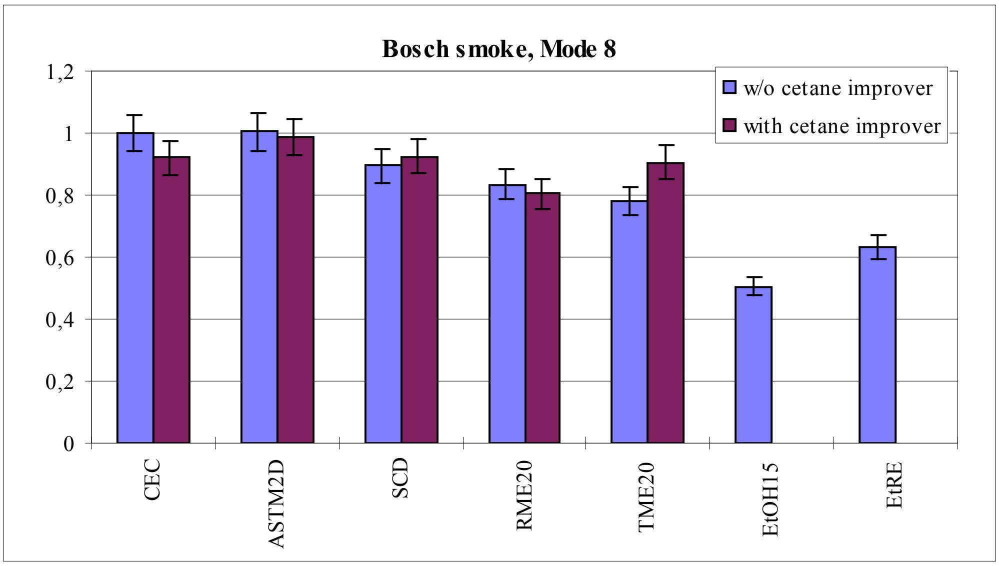


Figure 9. Bosch-smoke values with the heavy-duty VOLVO THD 103 KB engine at low load mode 2 and high load mode 8 of ECE R49 test procedure. Error bars represent standard deviations based on the highest deviations observed.

4.6 Combustion properties

The numerical results of the cylinder pressure parameters are given in Appendix 3.

An example of the cylinder pressure curve of the VOLVO THD 103 KB engine is given in *figure 10*. The loads presented in the figure are ECE R49 modes 6 (1 300 rpm, 100% load) and 8 (2 000 rpm, 100% load). The cylinder pressure curve is quite smooth. Typical for this engine is late injection (after TDC) and late combustion.

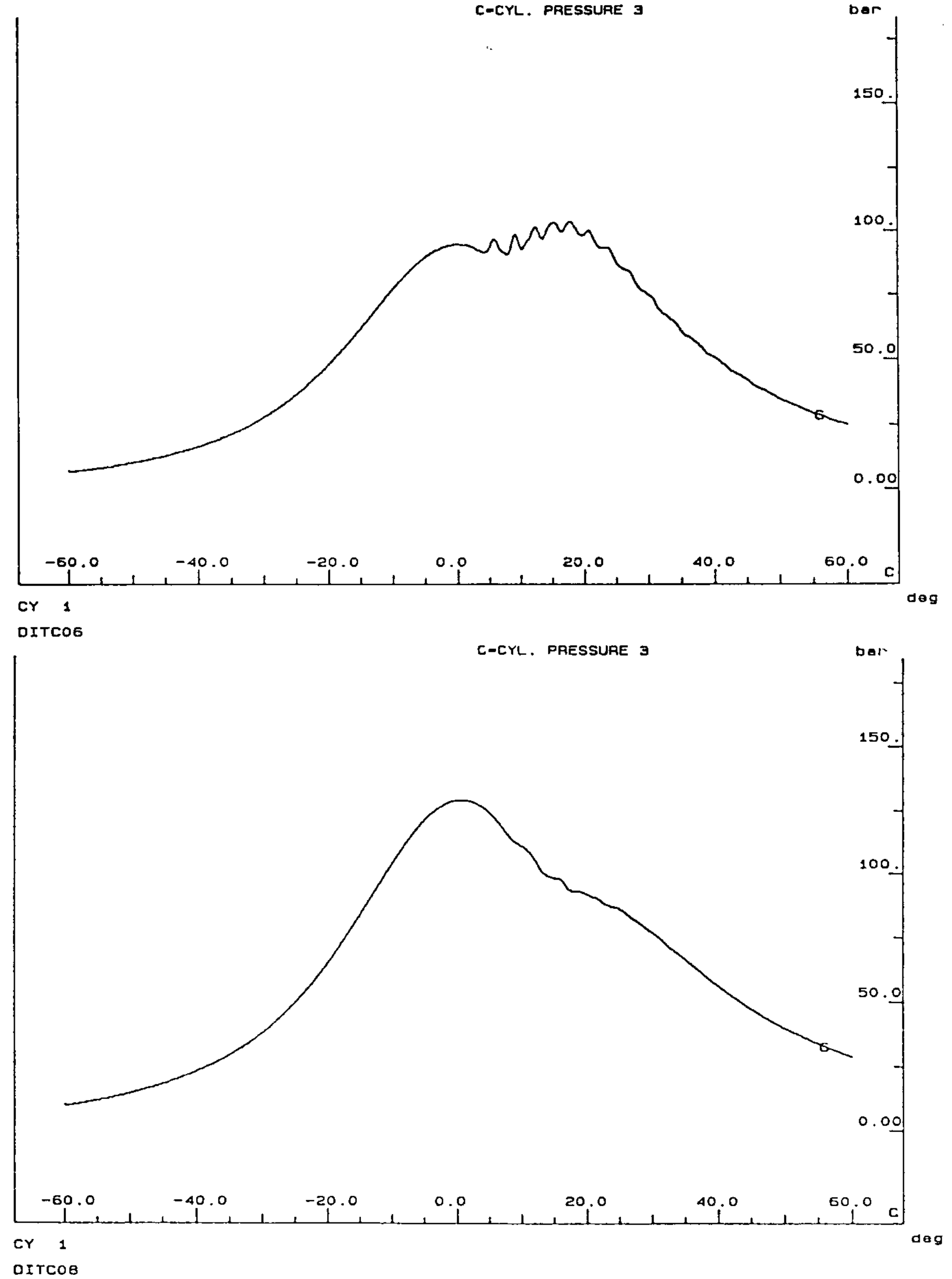


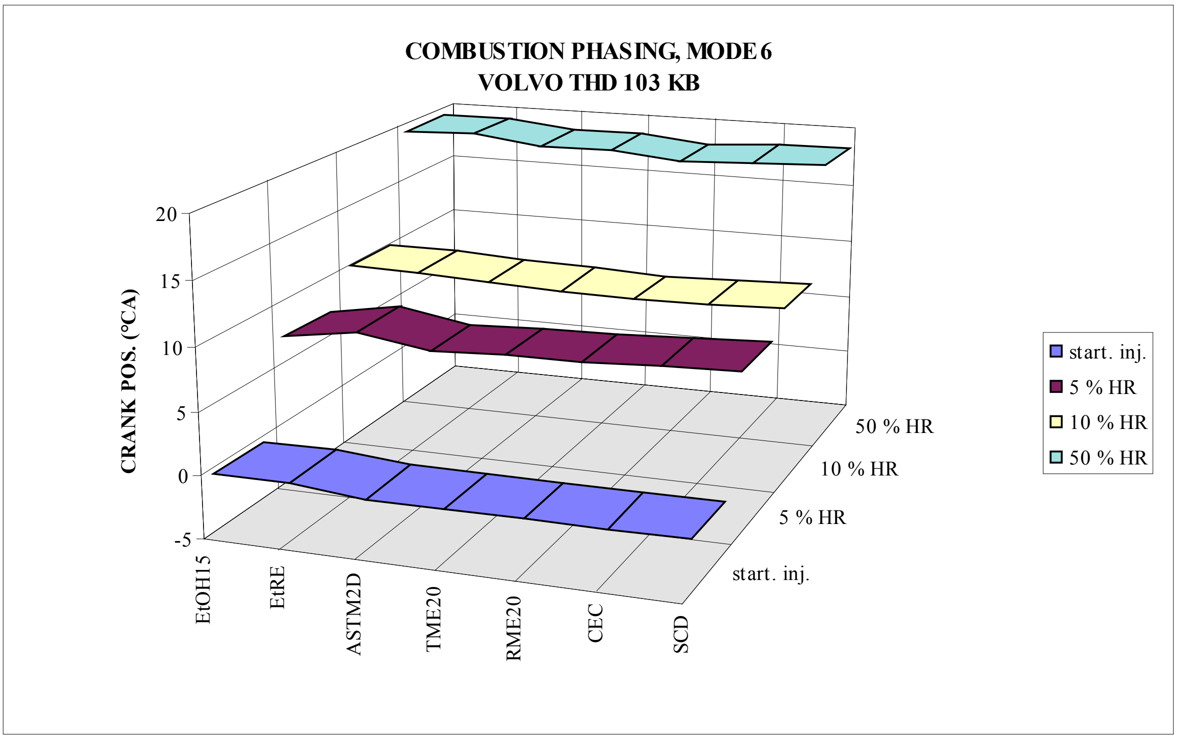
Figure 10. Cylinder pressure curves for the VOLVO THD 103 KB engine at ECE R49 modes 6 (1 300 rpm, 100% load) and 8 (2 000 rpm, 100% load).

The combustion parameters at different loads vary considerably. At high loads, where the temperature of cylinder is high, the ignition properties of the fuel are not as critical as at low loads. The start of injection and heat release parameters (5, 10 and 50 % HR) at low load mode 2 and high load mode 6 are shown in figure 11.

The fuels are presented in Figure 11 in increasing order of cetane number. It is observed that there is some correlation between the cetane number and the combustion parameters. However, one must bear in mind that the cetane number measurements for ethanol fuels gave variable results as described in chapter 3.

As mentioned earlier, the ignition properties of the fuel (cetane number) are most critical at low loads. If the cetane number is low, the ignition delay increases and there is a lot of fuel in the cylinder at the moment of ignition. This may lead to a very fast combustion process, almost explosive, which may also occur as diesel “knocking”. Delayed ignition and rapid combustion usually also result in higher emissions and noise. Combustion parameters with the different test fuels at low load mode 12 are shown in *figure 12*. It is seen from the figure, that the ignition delay is longest with ethanol and low cetane fuels, whereas the duration of combustion is shorter with low cetane fuels.

The same observation can be made when the fuels with and without the cetane improver are compared with each other. As an example a few comparisons of ignition delay and maximum pressure gradient at different modes of ECE R49 are shown in figure 13. It is clearly seen that the ignition delay is shorter and the maximum pressure gradient occurs earlier for the fuels with the cetane improver, which means that the combustion process is more stable and smooth. At high loads (modes 6 and 8) the differences between the fuels with and without the cetane improver are insignificant.



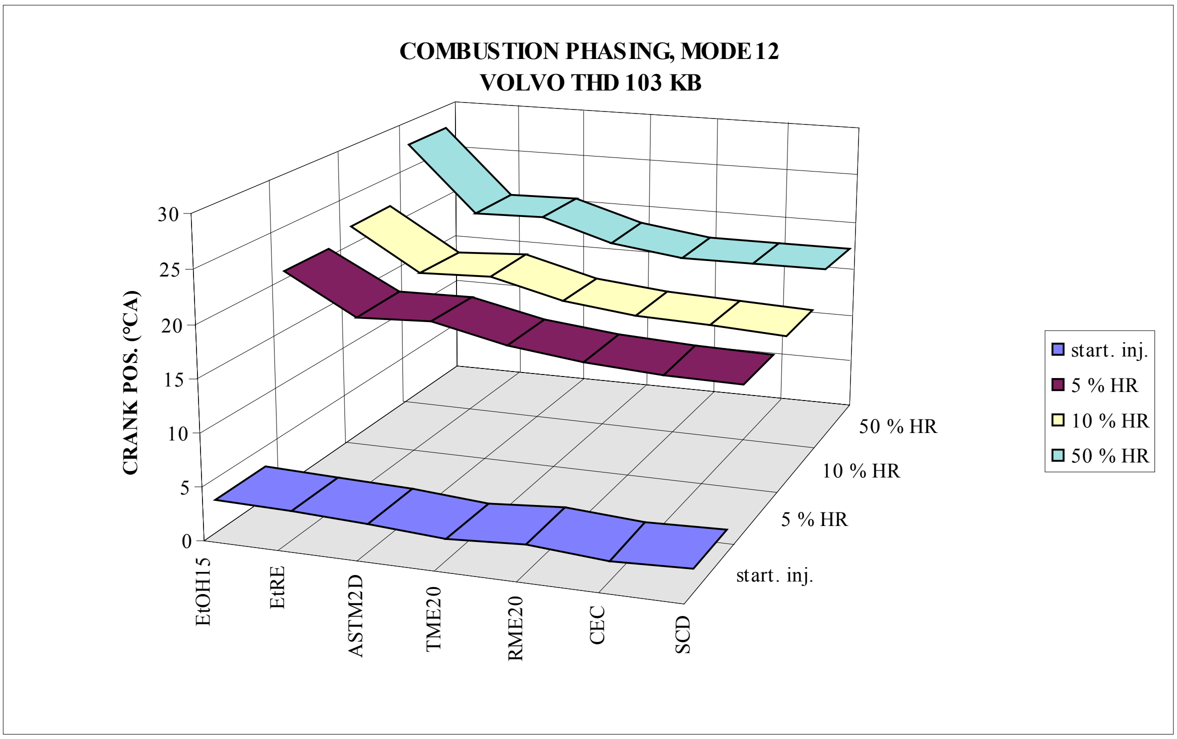


Figure 11. Start of injection, 5, 10 and 50% heat release of the test fuels with VOLVO THD 103 KB engine at high load mode 6 and low load mode 12 of ECE R49 test. The test fuels are presented in increasing order of cetane number.

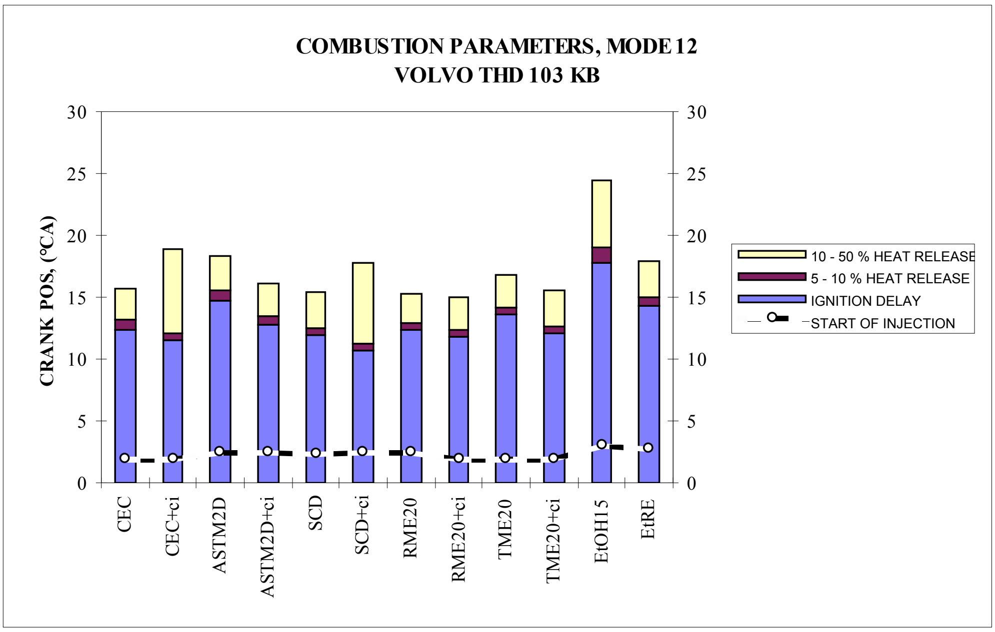


Figure 12. Combustion parameters at low load mode 2 of ECE R49 test with VOLVO THD 103 KB engine. The ignition delay is longest for the low cetane fuels.

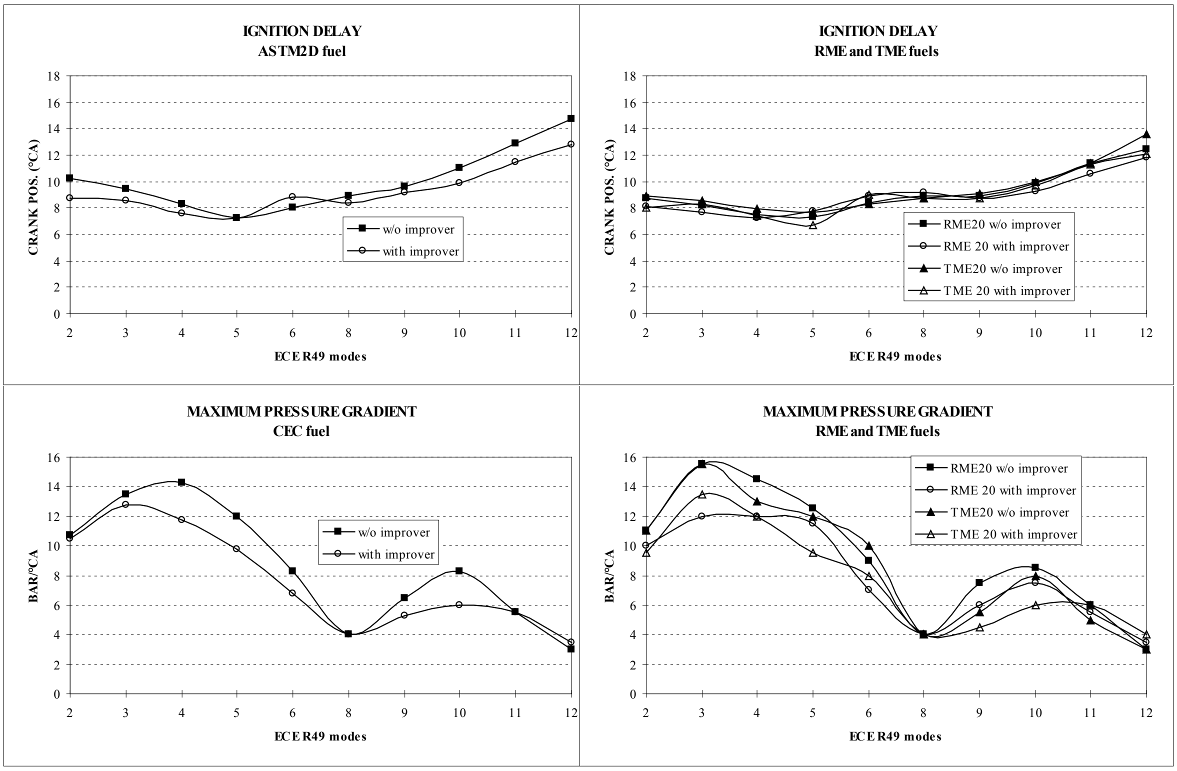


Figure 13. Ignition delay and maximum pressure gradient at different loads of ECE R49 test with the VOLVO THD 103 KB engine. Ignition delay is shorter, when the cetane improver additive is used.

5 Heavy-duty tests, VALMET 612 DWI

5.1 Engine, test procedure and program

Engine

The engine used in the tests was an Euro 2 emission level medium heavy-duty Valmet engine:

Identification	*VALMET 612DWI, vertical engine for on and off-road applications, -96* *turbo-charged, direct-injection* *inter-cooled (air/air)*
Pump	*in-line pump*
Displacement	*7.4 litre*
Cylinders	*6*
Power output	*185 kW / 2100 rpm, 1050 Nm / 1200 rpm*

The engine is equipped with an electrical inlet air heater to facilitate cold starting, but this device was not used.

Equipment

The tests with the VALMET 612 DWI engine were linked with the cold operability tests described later in chapter 9. For this reason also the 612 engine was located in the cold test cell, and the engine was run both at normal room temperature and at low temperatures.

The engine dynamometer was manufactured by Froude Consine Ltd (max. 165 kW). A set of mobile emission analysers were used for the tests. The NO_x analyser was manufactured by Thermo Electron Corporation, HC analyser by J.U.M. Engineering and CO analyser by ADC.

The equipment used for cylinder pressure analysis was the same as in chapter 4.

Test procedure

The analyses of cylinder pressure and emissions were carried out at the following loads:

1. intermediate speed (1 185 rpm), 25% load
2. intermediate speed (1 185 rpm), 50% load
3. rated speed (2 070 rpm), 25% load
4. rated speed (2 070 rpm), 50% load

Low load levels were used to accentuate the effect of fuel ignition properties on the results. The engine was warmed up by running different loads for at least 15 minutes. The engine was running at each load for 6 minutes. The emission data was recorded in one-second intervals.

The cylinder pressure measurement was carried out as explained in chapter 4. The only exception was the calculation principle of ignition delay. The cylinder pressure trace of the VALMET is “classic diesel”, with a very sharp increase in cylinder pressure after ignition (see *figure 14*). Therefore start of combustion can be determined using the Indiskop algorithm for diesel engines based on the instantaneous heat release curve.

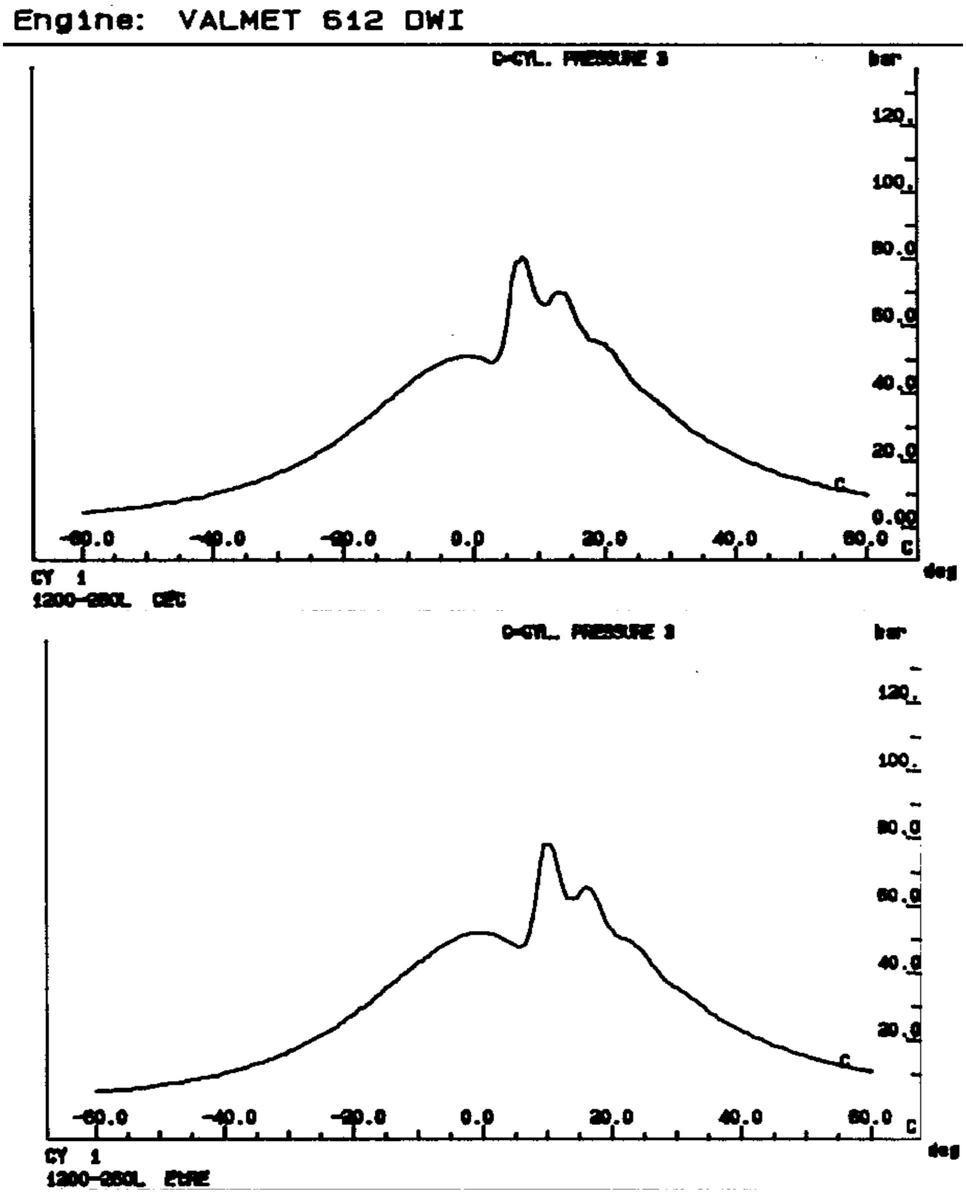


Figure 14. Cylinder pressure curves for the VALMET 612 DWI engine at intermediate speed, 50% load with CEC and EtRE fuels.

In the emission measurements only regulated pollutant concentrations were measured. As the emission tests were run in fixed load points, it was considered that a comparison of pollutant concentrations was sufficient to compare the fuels to each other.

Test programme

All fuels of base fuel matrix with and without the cetane improver were tested (*CEC, CEC+ci, ASTM2D, ASTM2D+ci, SCD, SCD+ci, RME20, RME20+ci, TME20, TME20+ci, EtOH15, EtOH15+ci, EtRE, EtRE+ci*). The analysis included regulated gaseous emissions and cylinder pressure analysis.

5.2 Results from the emission tests

The results are presented in Appendix 4 and in Figures 15 and 16 (pollutant concentrations only).

At all loads tested, the CO concentration was highest for ethanol containing fuels. At 25% loads at both engine speeds, EtRE gave lower CO concentrations than EtOH15. ASTM 2D and TME20 gave slightly higher CO levels than CEC, SCD and RME20. The cetane improver additive reduced CO concentrations clearly at 25% load at both engine speeds.

The HC concentrations were highest for ASTM 2D without the cetane improver at all load points studied, except for rated speed 25% load, at which the ethanol fuels gave the highest HC concentrations. There was significant variation in the order of test fuels at different loads in respect of HC concentrations. Consequently, it is difficult to draw any conclusions from the HC results.

The NO_x concentrations of the CEC fuels were highest at all loads studied. The differences in the NO_x concentrations of the other fuels than CEC are not significant. The cetane improver additive did not to affect the NO_x concentration with the VALMET 612 DWI engine.

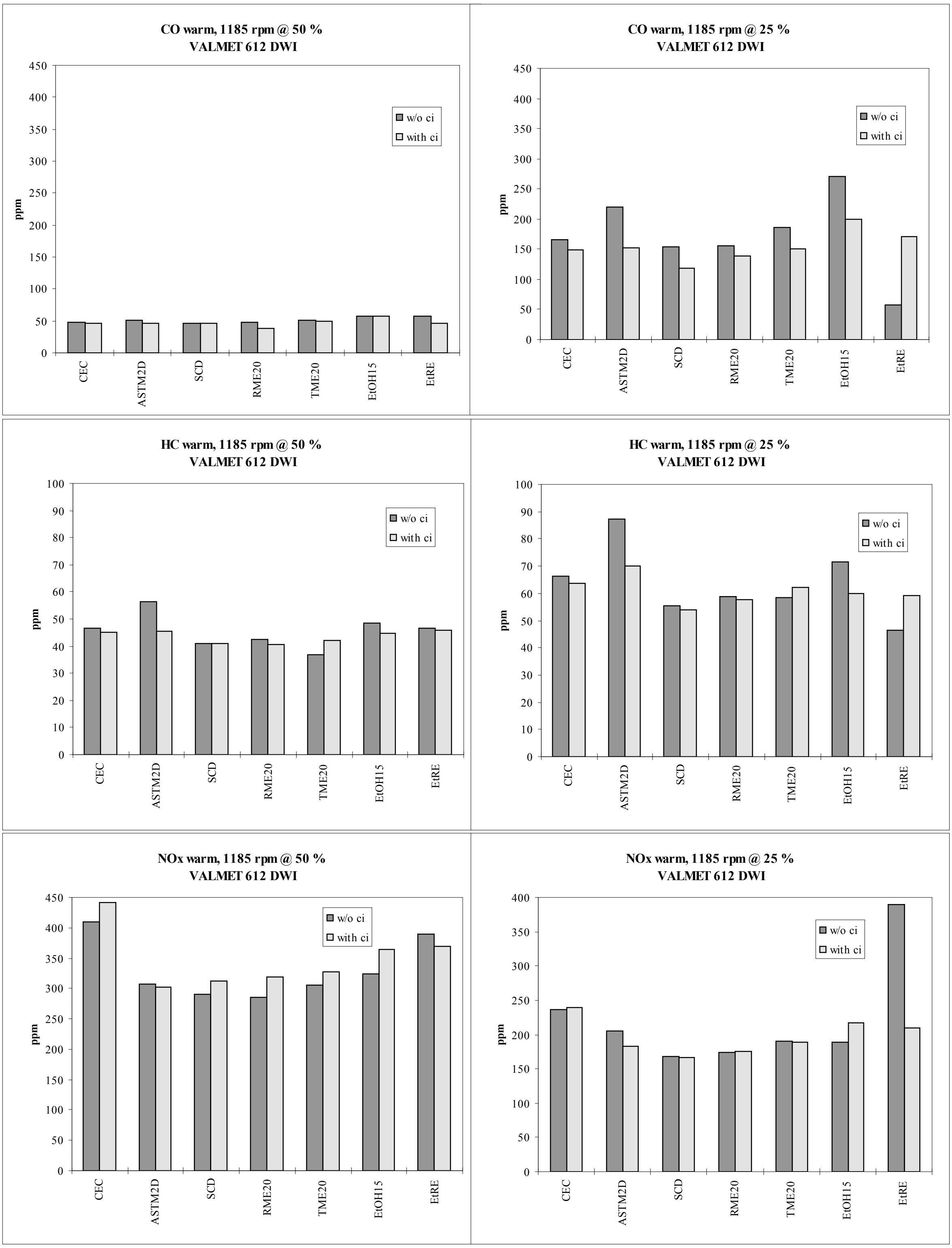


Figure 15. CO, HC and NO_x concentrations at intermediate speed, 50 and 25% loads with the Valmet 612 DWI engine.

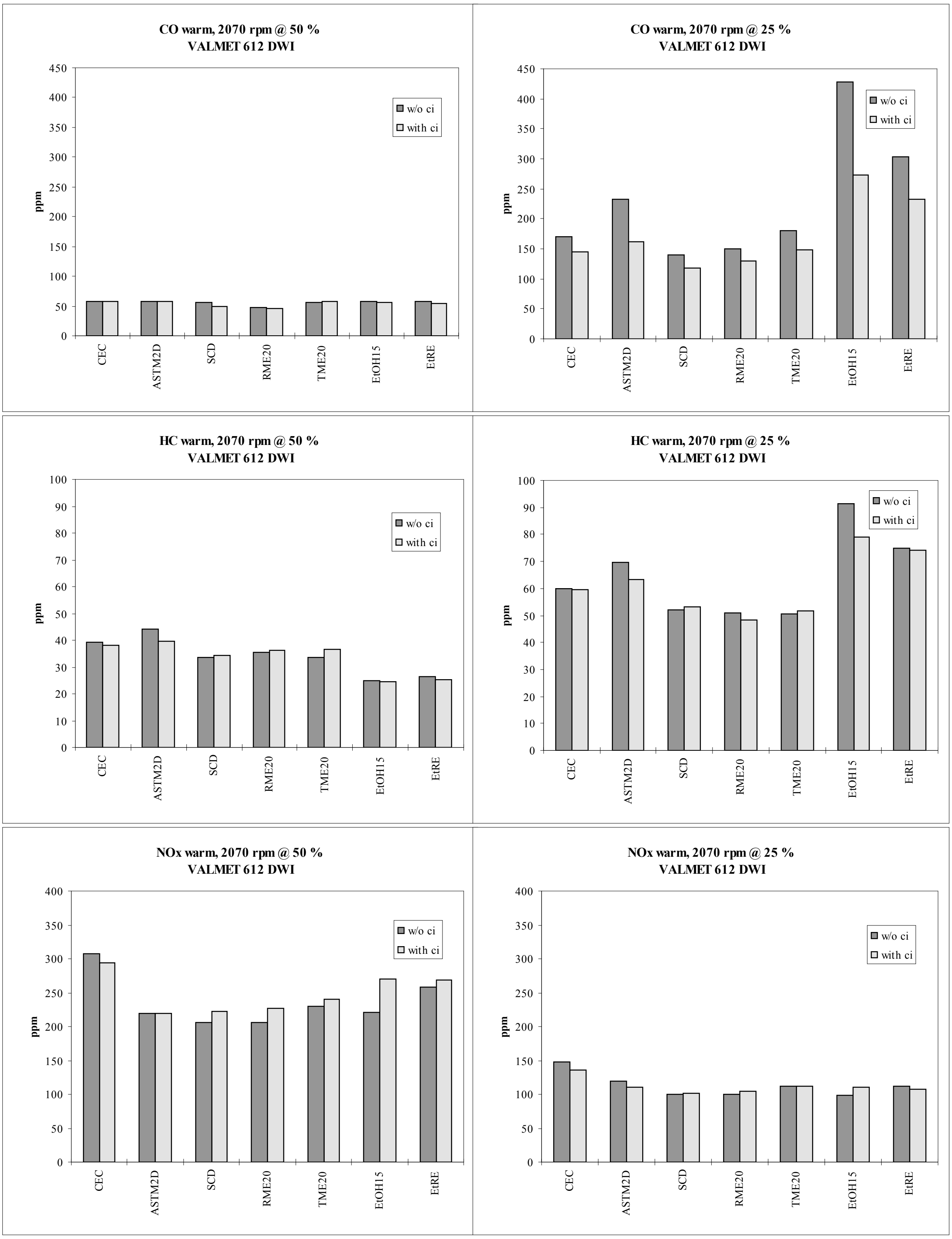


Figure 16. CO, HC and NO_x concentrations at rated speed, 50 and 25% loads with theValmet 612 DWI engine.

5.3 Combustion properties

The results of the cylinder pressure analysis are presented in Appendix 5 and Figures 17 and 18.

The basic injection timing of the VALMET 612 DWI engine was about 8 °CA before top dead centre (BTDC). According to the needle lift measurement, dynamic injection timing ranged from 5 to 0 °CA BTDC depending on load.

The increase in cylinder pressure was very sharp with VALMET engine (this was described in chapter 5.1, figure 14). The results for crank angle at 5% heat release varied strongly, and therefore the results of combustion phasing are not presented here.

The combustion parameters at intermediate speed, 25% and 50% loads are shown in figure 17. It is seen from the figure, that the start of injection for the ethanol fuels begins much later than for the other fuels at 25% load. In the VALMET engine ignition delay was in general long, but the actual combustion process very rapid.

The cetane improver additive had a clear effect on the ignition delay and maximum pressure gradient. As an example, the ignition delay and pressure gradient for the RME20 fuel with and without the cetane improver at different loads is shown in figure 18. It is clearly seen that the ignition delay is shorter and the maximum pressure gradient occurs earlier with the fuels with the cetane improver, which means that the combustion process is more smooth.

The effect of the fuel and cetane improver on the ignition delay and combustion process of the VALMET 612 DWI engine was very similar to that of the VOLVO THD 103 KB engine, although the combustion processes of these engines in general are rather different.

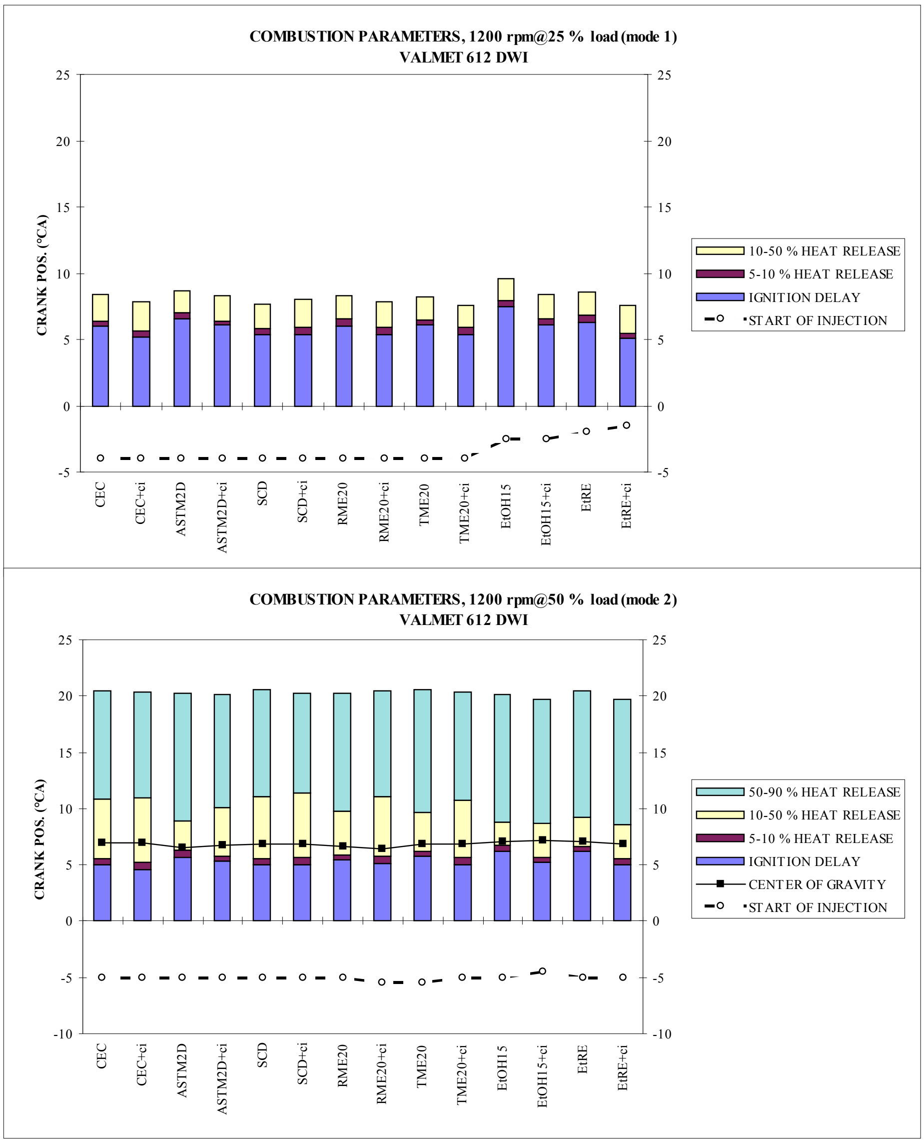


Figure 17. Combustion parameters at intermediate speed 25 and 50% loads for the VALMET 612 DWI engine. The ignition delay is longest for the low cetane fuels.

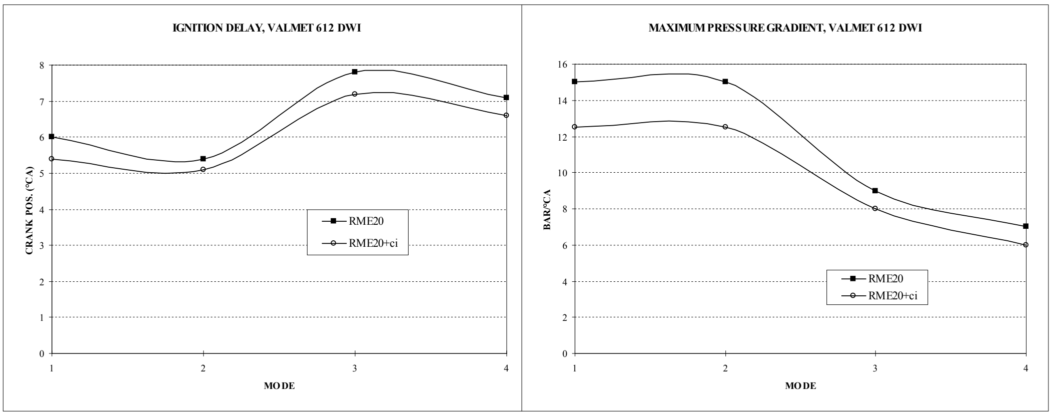


Figure 18. The ignition delay and maximum pressure gradient at different loads of ECE R49 test with VALMET 612 DWI. The ignition delay is shorter, when the cetane improver additive is used.

6 Light-duty vehicle tests, AUDI 1.9 TDI

6.1 Test vehicle

An Audi 1.9 TDI vehicle was used to screen the combustion properties and the effect of fuel quality on exhaust emissions of a modern light-duty vehicle. The vehicle was donated for the project by VAG Company.

The Audi 1.9 TDI represents the most advanced, direct-injection diesel technology for light-duty vehicles. One speciality of the vehicle is the needle-lift sensor, which detects the actual start of injection. Thus the control unit can maintain start of injection-values programmed into the system. The vehicle is also equipped with an advanced EGR system to reduce NO_x emissions. Air flow is measured with an air flow mass meter. The quantity of fresh air is used for calculating the EGR rate and the permissible quantity of fuel injected. This complicated engine technology causes some uncertainty in the evaluation of differences between fuel qualities.

The characteristics of the vehicle are as follows:

Identification	*AUDI 1.9 TDI, turbo-charged, 1995* *direct-injection, inter-cooled (water/air)*
Displacement	*1.9 litre*
Cylinders	*4*
Power output	*66 kW @ 4000 rpm*
Torque	*202 Nm @ 1900 rpm*
Gears	*automatic,4 speeds*
Compression ratio	*19.5:1*

Electronically controlled distributor injection pump
Equipped with EGR and oxidation catalyst

6.2 Test procedure and facilities

Test facilities and equipment

The regulated emissions were collected and measured with a system which fulfils the requirements of the 91/441/EEC directive and US FTP75 test procedure. The general layout of the test arrangements for light-duty testing at VTT is given in *figure 19*.

The tests were carried out in a climatic test cell equipped with a chassis dynamometer, a single-axle 1.0 m roller diameter DC-type dynamometer manufactured by Froude Consine. The flow of air through the windage simulation system was set at 25 km/h during the tests.

The emission and cylinder pressure measurement system was the same as described in chapter 4.

Figure 19. General lay-out of test arrangements for light-duty testing at VTT.

Steady-state test procedure

For the cylinder pressure measurements the vehicle was run in steady-state mode. To screen suitable load points, preliminary tests were run at several engine speeds with all gears of the automatic gear box. The results of these tests are presented in *table 4*.

Table 4. Speeds with different gears (automatic gear box).

rpm	**1. gear** km/h	**2. gear** km/h	**3. gear** km/h	**4. gear** km/h
1 500	19	32	43	55
2 000	23	40	64	86
2 500	30	54	96	108
3 000	38	66	97	128
3 500	42	78	112	
4 000	49	88	128	

The engine speed maximum was 4 300 rpm for 1st and 2nd gear. The lowest engine speed at which the automatic gearbox did not shift to a lower gear was 2 500 rpm, corresponding to 96 km/h for the 3rd gear and 108 km/h for the 4th gear.

The load points selected for testing are shown in *figure 20* and *table 5*. Corresponding load points are also included in the ECE R49 test cycle.

The vehicle was warmed up by running 100 km/h for about 15 minutes before the tests. The exhaust gases were collected with a constant-volume sampling method in five tedlar-bags. The collection time for each bag was 200 seconds. The cylinder pressure analysis was carried out during the last minute of each load.

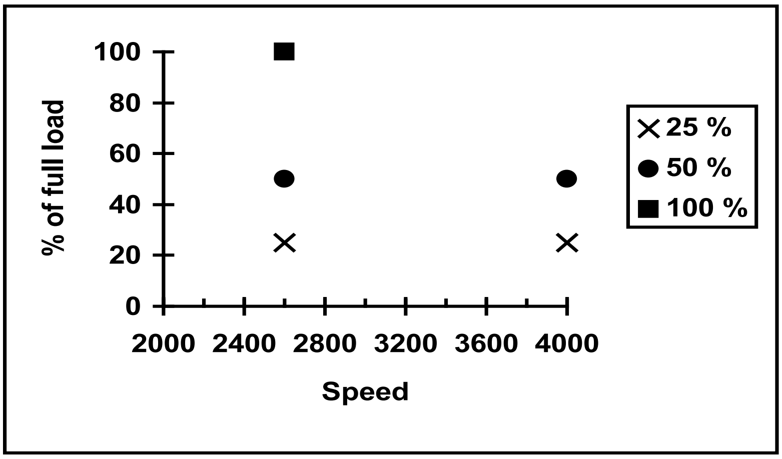


Figure 20. Steady-state load points used in the light-duty test programme.

Table 5. Summary of the light-duty steady-state modes.

Mode	Engine speed rpm	Load % of full load	Speed (km/h) 4. gear	Power (kW) / Force (N)
1	4 000	50	120	25 / 700
2	4 000	25	120	13 / 377
3	2 600	100	77	38 / 1 700
4	2 600	50	77	19 / 845
5	2 600	25	77	10 / 440

Transient tests

The transient tests are described in chapter 10. The results of FTP measurements are mentioned in this chapter only as a reference to steady-state emissions.

6.3 Test program

In addition to the base fuel matrix studied with the VOLVO THD 103 KB engine, also ethanol fuels with the cetane improver were tested. In the laboratory tests at VTT it was found out that the cetane improver designed for diesel fuels was soluble in ethanol emulsions.

Low and high cetane number reference fuels for the ASTM D 613 CFR test method for cetane numbers were tested to examine their behaviour in a real engine. Testing of the cetane reference fuels with a heavy-duty engine would have been too expensive, as the cetane reference fuels are mixed from expensive pure chemicals (n-heptane, iso-octane). The light-duty tests require only a small amount of fuel, and so it was possible to test these reference fuels.

The CEC fuel was tested three times during the testing period to study the stability of the vehicle and testing system.

The summary of the test programme for light duty tests is presented in *table 6*.

Table 6. Test programme of steady-state LD tests with the Audi 1.9 TDI vehicle.

Fuel	**No. of steady-state tests**	**Cylinder pressure analysis**	**Reg. emissions**
CEC: *CEC+ci:*	3 1	3 * 5 modes 5 modes	3 * 5 modes 5 modes
ASTM2D: *ASTM2D+ci:*	1 1	5 modes 5 modes	5 modes 5 modes
SCD *SCD+ci*	1 1	5 modes 5 modes	5 modes 5 modes
RME20 *RME20+ci*	1 1	5 modes 5 modes	5 modes 5 modes
TME20 *TME20+ci*	1 1	5 modes 5 modes	5 modes 5 modes
EtOH15 *EtOH15+ci*	1 1	5 modes 5 modes	5 modes 5 modes
EtRE *EtRE+ci*	1 1	5 modes 5 modes	5 modes 5 modes
CNref43 *CNref60*	1 1	5 modes 5 modes	5 modes 5 modes
SUM	18	90	
FTP results described later in chapter 10 are discussed here as a reference to emission results.			

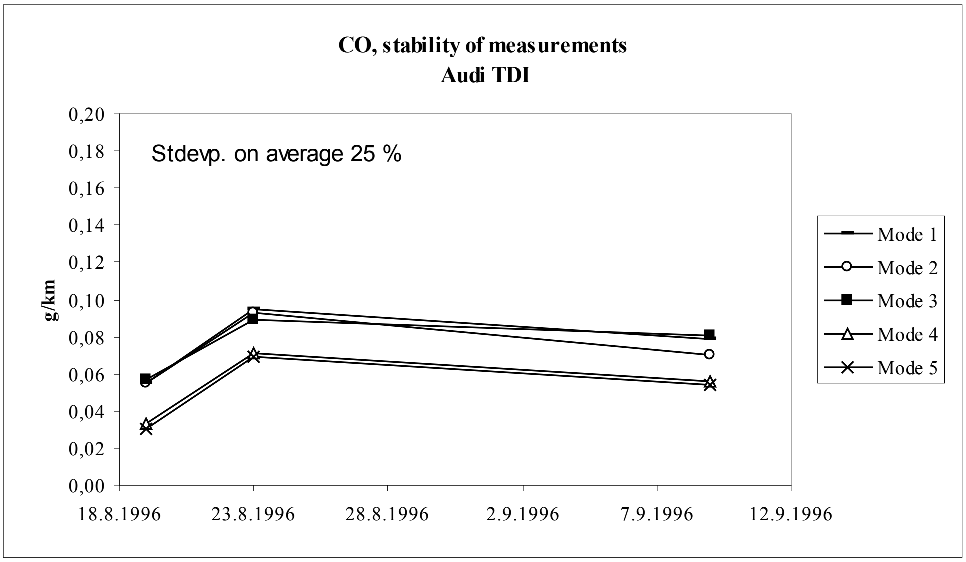
6.4 Gaseous regulated emissions

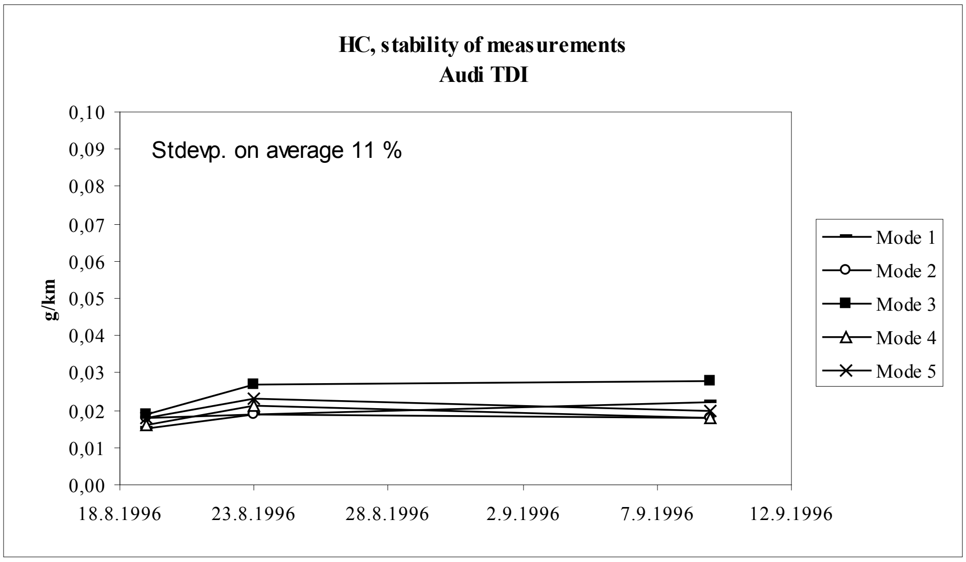
6.4.1 System stability and standard deviations

The stability of the test system was ensured by running CEC fuel several times during the testing period. The results of the stability measurements are presented in *figure 21*.

The gaseous emissions stayed at the same level, except for the CO emission, which increased significantly during the measuring period. The standard deviation of CO emission was on average 25%. The reason for variation of the CO emission was that the CO concentrations in the test bags were really low, about 10 ppm. The accuracy of the CO analyser is not good enough to give reliable comparative results from different tests at this concentration level. Hence, the CO results cannot be considered when assessing the results.

The measurement of HC emission was much more reliable than that of CO emission, standard deviation being about 11%. However, the HC emission level was also low, less than 10 ppm in the test bags. The accuracy of the HC analyser is better than that of the CO analyser. Hence despite the low concentration level the HC results can be taken into account.





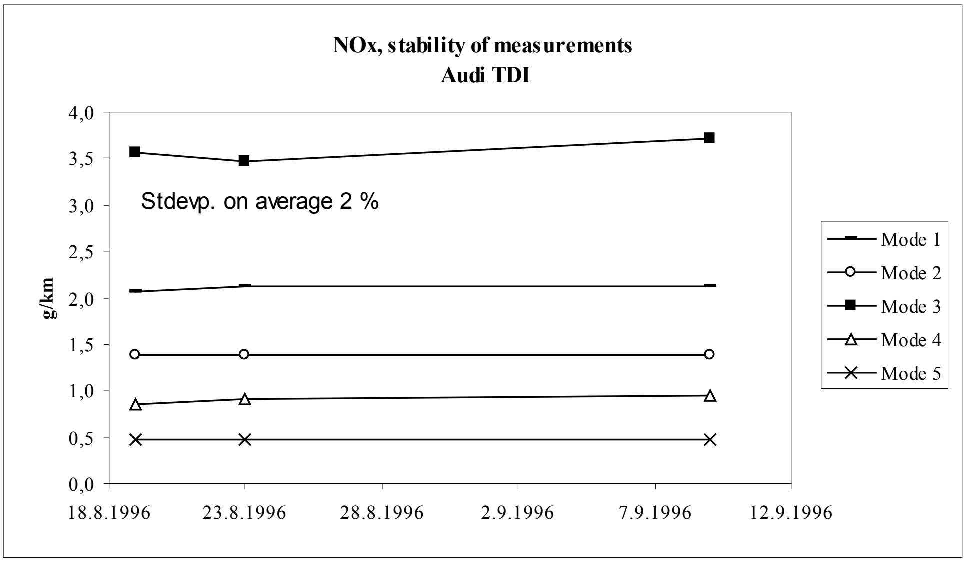


Figure 21. Stability of the measuring system over the testing period, steady-state tests with Audi 1.9 TDI.

The repeatability of the NO_x measurement was best, the standard deviation being on average only 2%. The NO_x concentrations in the test bags were high enough to give reliable results.

6.4.2 Gaseous regulated emissions

The numeric results of the gaseous emission measurements at each steady-state load point are presented in Appendix 6. The emissions with test fuels with and without the cetane improver are shown on average for 5 steady-state modes in *figure 22*.

The stability tests with the CEC fuel (chapter 6.4.1) showed that the CO emission concentrations in the test bags were too low to give reliable results and hence are not considered.

The most significant difference between the different fuel qualities were the extremely high HC emissions from the ethanol fuels, i.e. about threefold compared to those from the other fuels. On the other hand, the real-life test cycle, FTP test (chapter 10), gave only some 40% increase in the HC emission compared with the CEC fuel. For some reason, the engine-out HC level is so high for the ethanol fuels that the oxidation catalyst fails to oxidise them efficiently. However, the HC emission level of this diesel vehicle is so low that even high relative increases are insignificant in absolute terms (g/km). Some small differences were observed for the other fuels. The HC emissions decreased by about 10% when the ester fuels were compared with the CEC fuel. Cetane improver performed differently in RME and TME fuels. In the FTP test the results were contrary to those of the steady-state tests: RME20 gave some 10% higher HC emissions than the CEC fuel and the cetane improver reduced the emission by about 40%.

The only low-cetane conventional fuel, ASTM 2D, seemed to give higher HC emissions than the other hydrocarbon fuels, which was also the case in heavy-duty tests (chapter 4). The effect of the SCD fuel on the HC emission was insignificant.

The cetane reference fuels CNref60 and CNref43 gave much higher HC emissions than the conventional fuels. In addition, the HC emissions from the high-cetane number reference fuel was twice that from the low-cetane number reference fuel, which is contrary to the expectation. The reason for this might be found in the low volatility of the reference fuels. The high-cetane fuel has a higher boiling point than the low-cetane reference fuel. The cetane reference fuels seem to be unsuitable for advanced diesel LD vehicles. The CFR engine is not as sensitive to volatility and the engine speeds are very low compared with those of a four-cylinder vehicle.

There were no really significant NO_x emission differences between the test fuels, although the measurement of NO_x was very accurate. The ethanol fuels did not reduce the NO_x emissions as in a heavy-duty engine. This was also verified by FTP tests. This was probably due to the EGR system, which reduces overall NO_x emissions of the vehicle and hence the effect of the fuel is not so significant. One contributing factor is also the feedback from the needle lift sensor: start of injection is more or less constant independent of the fuel.

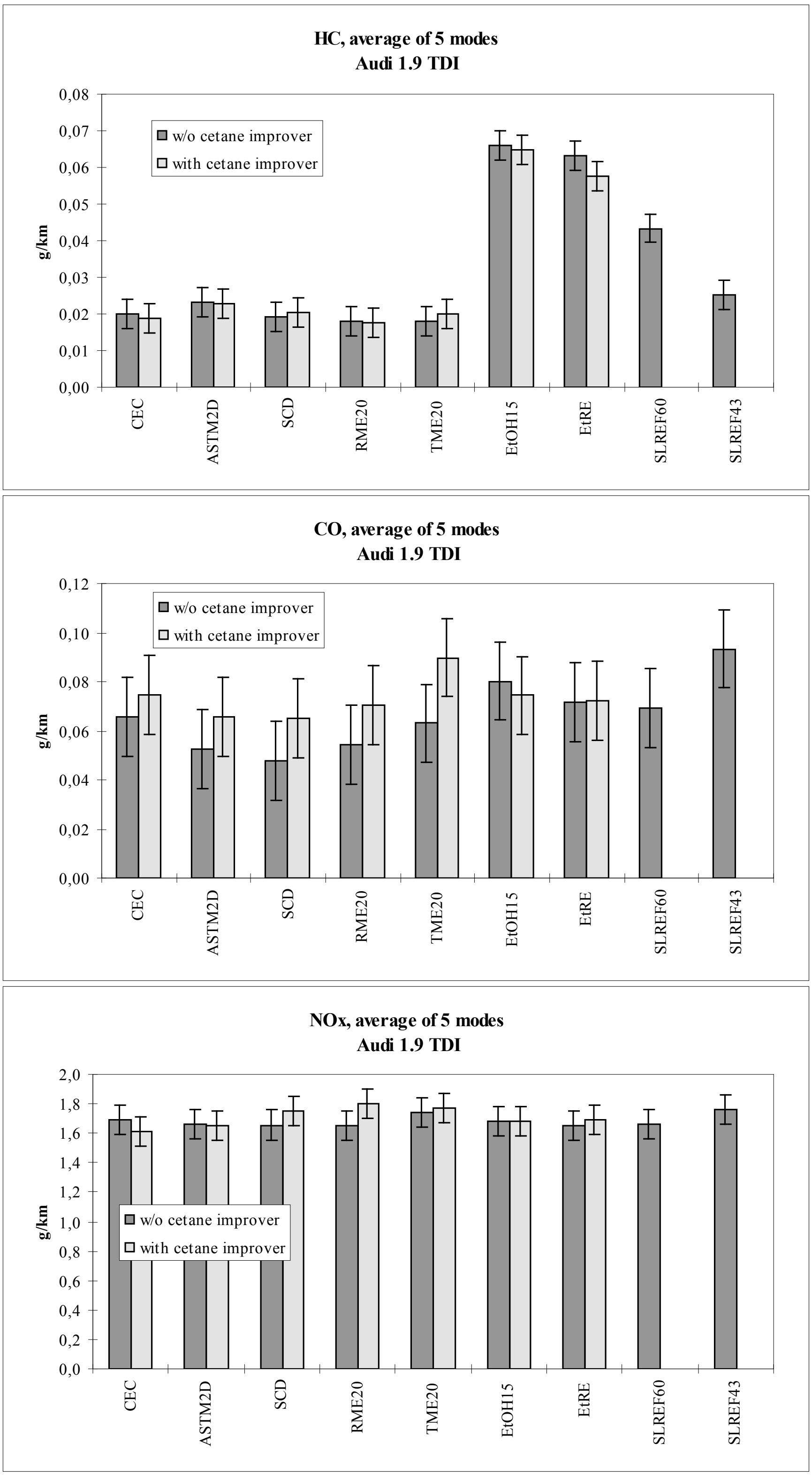


Figure 22. The regulated emissions from Audi 1.9 TDI on average for 5 steady-state loads. The error bars represent standard deviations with the CEC fuel measured three times during the testing period.

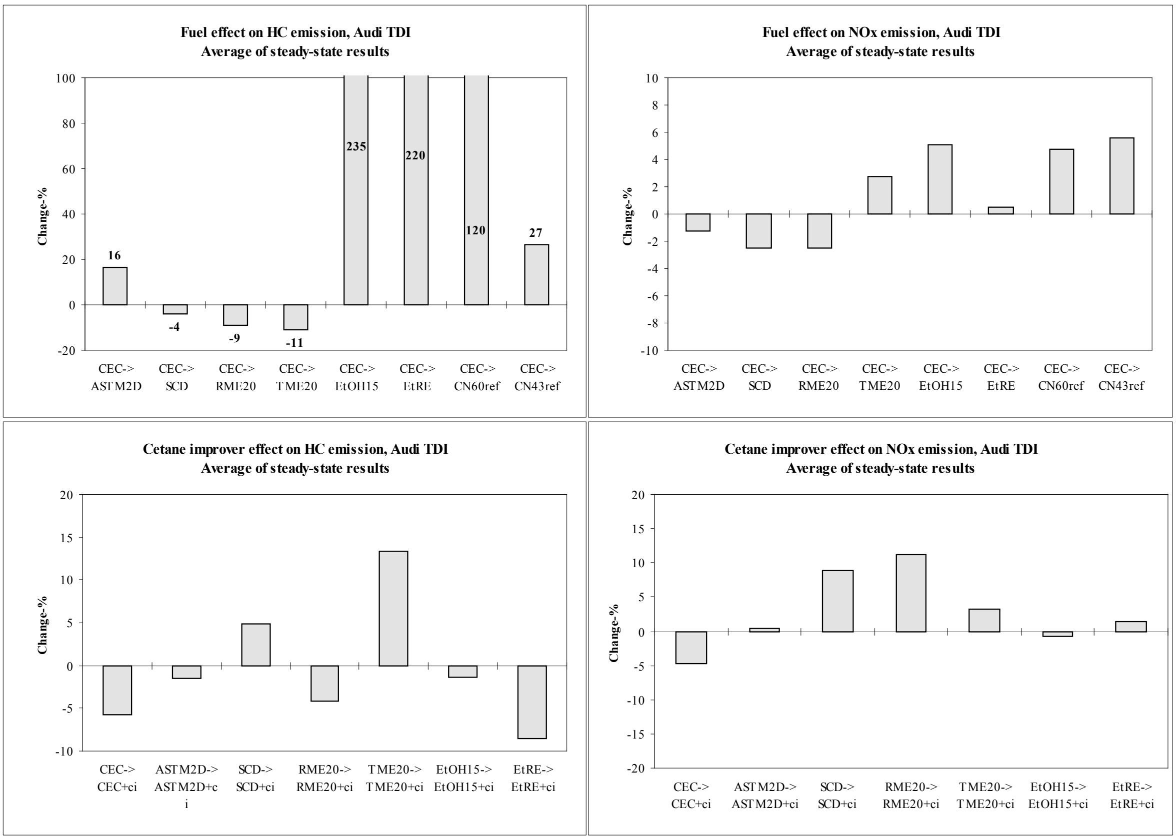


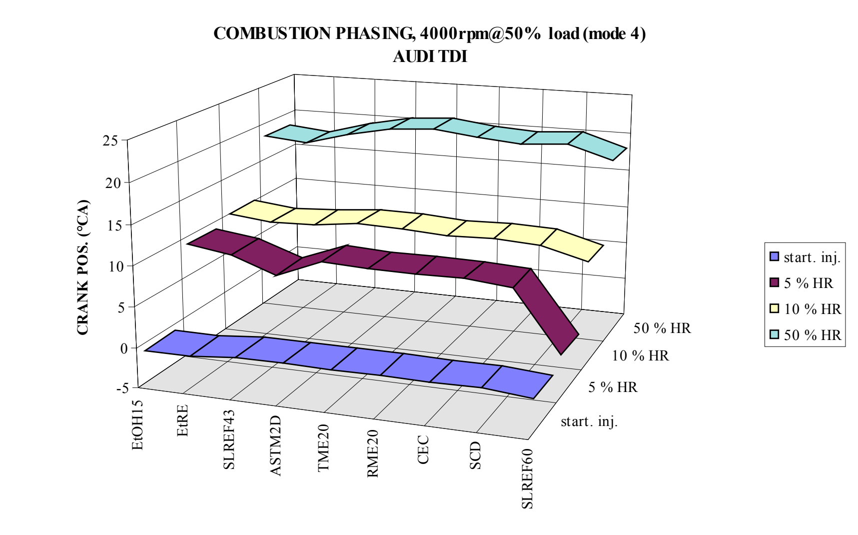
Figure 23. HC and NO_x-emission changes in Audi 1.9 TDI steady-state tests. Changes of less than 10% for HC are insignificant.

6.5 Cylinder pressure analysis

The Audi 1.9 TDI engine was instrumented for cylinder pressure analysis with basically the same equipment as described for heavy-duty measurements in chapter 4. Also the same parameters were measured. Start of combustion was determined in the same way as for the VOLVO engine.

The cylinder pressure parameters did not change over the testing period in same way as CO emission. There were some significant differences in one or two load points occasionally, but no systematic changes. However, it is apparent that these unsystematic differences make it more difficult to analyse these results than those of the heavy-duty results, which were repeatable and logical. The differences can originate from the active injection timing control system.

The numeric results of the cylinder pressure analysis is presented in Appendix 6. The start of injection and the 5%, 10% and 50% heat release parameters for the base fuel matrix and cetane reference fuels are shown in *figure 24*. The fuels are presented in an increasing order of cetane number. There seem to be no clear linearity between the cetane number and heat release parameters. The 50% heat release level seems to be reached faster with the ethanol fuels than for the other fuels. In the heavy-duty tests it was on the contrary: 50% heat release was achieved later with the ethanol blends than with the other fuels.



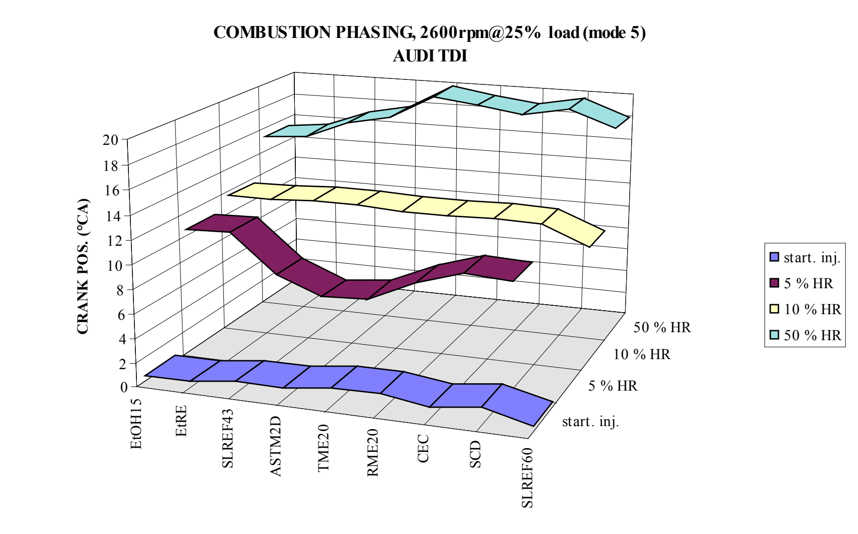


Figure 24. Combustion parameters of the test fuels with Audi 1.9 TDI vehicle at loads 4000 rpm / 50 % load (mode 1) and 2600 rpm / 25 % load (mode 5). The test fuels are presented in increasing order of cetane number.

The differences between the test fuels are smaller at high load mode than at low load mode. At low load mode 5, it is clearly seen that the ignition delay is longer for the ethanol fuels than for the other fuels, and after ignition the ethanol fuels burn very fast resulting in the shortest duration of combustion.

The effect of the cetane improver is not seen as clearly as in heavy-duty tests. However, some fuels, especially the ester-blended fuels, which had a very high response for the cetane improver, seemed to have a somewhat shorter ignition delay with than without the cetane improver additive. The ignition delays of the ester-blended fuels, the low-cetane ASTM 2D fuel and the EtOH15 fuel are shown in *figure 25*. The differences are greatest at low load modes 4 and 5 (2 600 rpm 50 and 25% loads).

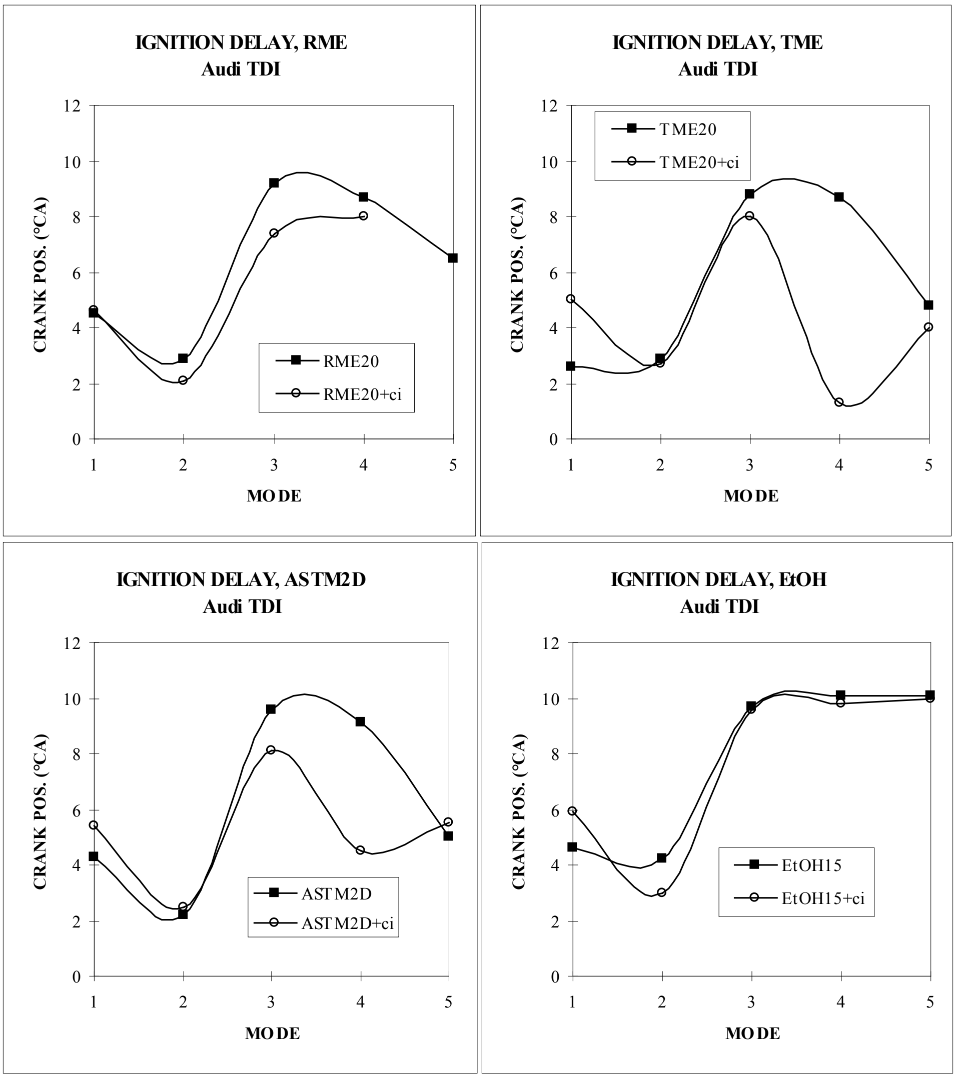


Figure 25. Some examples of the ignition delay with and without the cetane improver, Audi 1.9 TDI steady-state tests. Modes 1 and 2 mean 50 and 25% loads at rated speed. Modes 3, 4 and 5 are 100, 50 and 25% loads at intermediate speed.

7 Suitability of traditional cetane number measurement for alternative diesel fuels

The cetane number measurement, ASTM D 613, has been developed to study ignition properties of the fuels. Ignition in a diesel engine occurs after a certain time period after fuel injection, which is called ignition delay. The autoignition requires high temperature in the cylinder, which is obtained by high compression pressures. Normally, if the cetane number of the fuel is high enough, ignition occurs after a moderate ignition delay period. Delayed ignition can be caused also by many other factors than a poor cetane number, e.g. low air temperature, poor fuel spray formation or wrong fuel/air mixing ratio.

If the ignition is delayed, there is much unburned fuel accumulated in the cylinder during the ignition delay period. Then when ignition takes place, the combustion process is rapid resulting in high peak pressures. The effects in practice, due to poor ignition quality of fuel, long ignition delay and high peak pressure, are:

- higher emissions
- noise, diesel knocking
- increased white smoke at low temperatures
- increased mechanical and thermal stresses on the engine

The effect of poor ignition properties on fuel combustion properties are most prominent at low engine loads. If the load is high, the temperature of the cylinder is so high that even poor ignition property fuels tend to autoignite at an optimum ignition delay.

The previous chapters included emission and cylinder pressure results for the different fuels. Now the results are summarised in order to find a correlation between fuel properties and engine performance. The fuel properties are screened for effects on emissions and combustion parameters.

One of the most certain conclusions is that the cetane number measurement is not suitable for ethanol emulsions. This was already concluded in chapter 3. The CFR engine used in the cetane number determination did not run properly with the ethanol fuels. Its running was unstable, and the cetane number for the same ethanol fuel quality varied significantly.

Correlation analysis was used to study which parameters affect the combustion of hydrocarbon fuels and alternative fuels. If, for example, the correlation between CFR cetane number and engine performance is good for hydrocarbon fuels, but no correlation is found for alternative fuels, it may be concluded that the CFR cetane number measurement does not give a true picture of performance of alternative fuels.

Linear regression was used to screen correlation (Excel spread-sheet calculation, Pearson correlation coefficient). If correlation is strong, the so called Pearson correlation coefficient R^2 is close to 1.0, However, the correlation factor does not necessarily tell the whole truth. If one result is very far away from the group of the other results, the correlation factor is high, although no real correlation exists. Therefore, some strong correlations are presented graphically in this chapter. The correlation results are summarised in Tables 7 - 9.

The correlations varied for some parameters at different loads. As the light loads are most critical for the ignition process, they were given the main attention. Correlations were evaluated using graphs, two examples of which are given in *figure 26*. The markings of correlation in the summary tables are more or less subjective interpretations of the results (see table 7) .

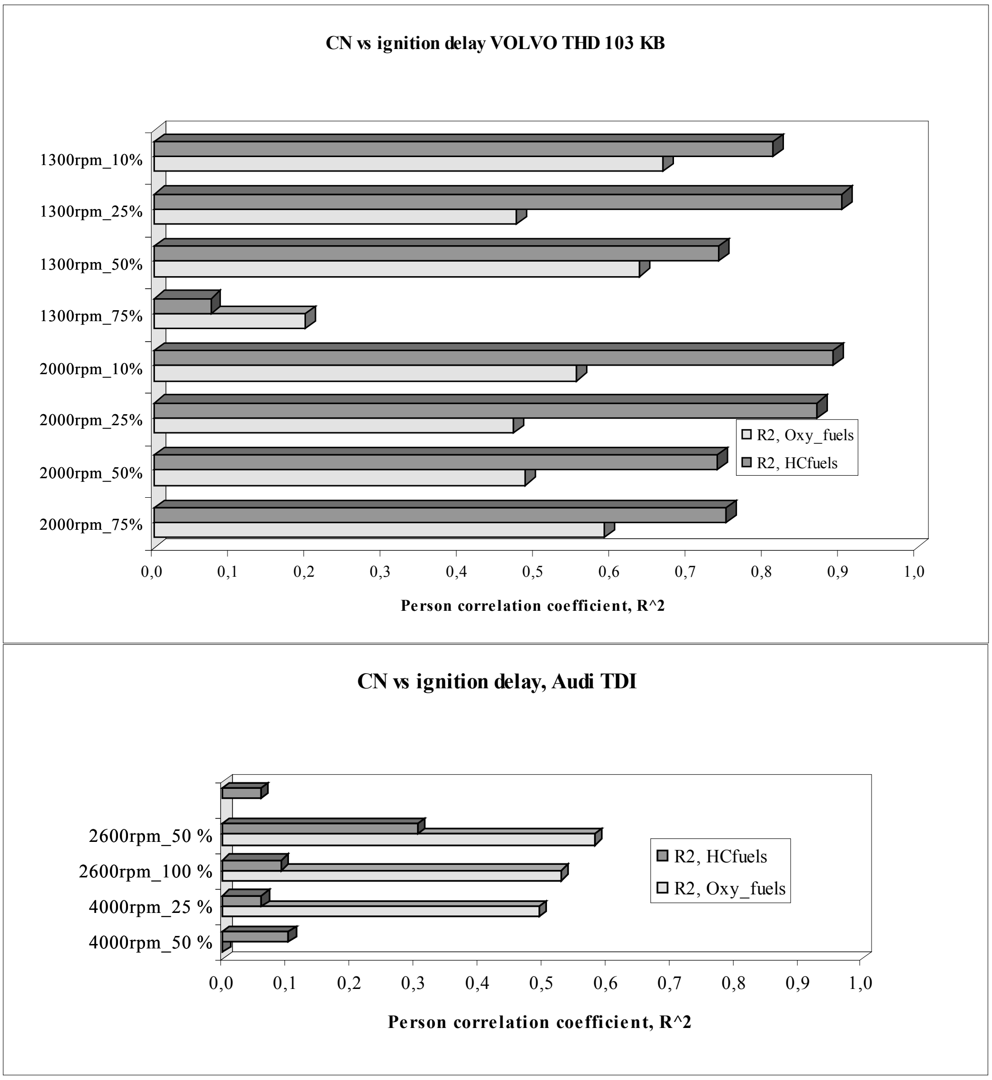


Figure 26. Two examples of the method, by which the correlation factors were evaluated for the summary in Tables 7 - 9.

For the VOLVO THD 103 KB heavy-duty engine the correlations (*table 7, figure 28*) of cetane number with ignition delay, maximum pressure gradient and heat release values were rather strong both for the hydrocarbon and alternative fuels. The cetane number did not correlate well with the CO and HC emissions from the hydrocarbon fuels, although some correlation was found with the alternative fuels, mainly due to the ethanol fuels. The cetane number correlated rather well with NO_x emissions with both fuel groups.

The emissions are known to be affected by the cetane number. Therefore, the correlations of emissions with combustion parameters were studied as well. Several correlations were found with the NO_x and CO emissions and combustion parameters for the VOLVO engine. The formation of NO_x is a rather complicated process and it cannot be conclusively said that the correlations would be only due to ignition properties of fuels. E.g., the effect of fuel chemical composition, especially aromatics, is known to have a great influence on NO_x. Physical properties, like density and viscosity may also change dynamic igntion timing and thus also NO_x emissions.

Table 7. Correlations at low and medium loads, VOLVO THD 103 KB.

	CN vs		**NOx vs**		**CO vs**	
	HC fuels	**Oxy fuels**	**HC fuels**	**Oxy fuels**	**HC fuels**	**Oxy fuels**
CO*	+	+				
HC*	0	++				
NOx*	++	+				
start of injection	+	+	+	0	+	+
peak value	+	0	+	0	+	0
max gradient	++	+	+	+	++	+
IMEP	0	0	0	0	0	+
ignition delay	++	+	++	+	++	++
5%HR	++	+	++	+	++	++
10% HR	++	+	++	+	++	++
50%HR	+	0	+	0	0	0

0 = no correlation + = slight correlation, $R^2 > 0,5$ ++ = rather strong correlation, $R^2 > 0,8$
*) ECE R49 mode 3 was studied for emission correlations.

The correlations observed for the VALMET 612 DWI engine were very similar to those for the VOLVO engine (*table 8*). Several strong correlations were found both for hydrocarbon and alternative fuels. As an example, the correlation of ignition delay versus cetane number is presented in *figure 29*.

Ignition delay of the Audi TDI did not correlate with the cetane number even with the hydrocarbon fuels (*table 9, figure 30*). Variation in ignition delay was high, 6 °CA, but the results were not logical. The maximum pressure gradient gave a better correlation for the hydrocarbon fuels than the ignition delay. None of the studied combustion parameters correlated with the cetane number.

The only strong correlations with the Audi TDI were found between emissions and combustion parameters. Even with these, it must be borne in mind that the results with the fuels fell mainly into two groups, and thus the correlations are not very significant even if Pearson factors are near to 1.0.

Table 8. Correlations at low and medium loads, VALMET 612 DWI.

	CN vs		CO vs		HC vs	
	HC fuels	**Oxy fuels**	**HC fuels**	**Oxy fuels**	**HC fuels**	**Oxy fuels**
CO	+	+	-	-		
HC	+	+	-	-		
NOx	0	0	-	-		
start of injection	0	0	0	0	0	+
peak value	++	++	+	+	+	0
max gradient	++	+	+	+	+	0
IMEP	0	0	0	0	0	0
ignition delay	++	+	+	+	+	+
5%HR	++	+	+	+	++	+
10% HR	++	+	+	+	++	+
50%HR	+	+	++	++	++	++

0 = no correlation   + = slight correlation, $R^2 > 0,5$ ++ = rather strong correlation, $R^2 > 0,8$

Table 9. Correlations at low and medium loads, AUDI TDI. None of the correlations were significant.

	CN vs		NOx vs		HC vs	
	HC fuels	**Oxy fuels**	**HC fuels**	**Oxy fuels**	**HC fuels**	**Oxy fuels**
CO	0	0	-	-		
HC	0	0	-	-		
NOx	0	0	-	-		
start of injection	0	0	0	0	0	+
peak value	0	0	+	0	+	+
max gradient	0	0	0	0	0	0
IMEP	0	0	0	0	0	++
ignition delay	0	0	0	0	0	0
5%HR	0	+	0	0	+	+
10% HR	+	+	+	0	0	0
50%HR	0	0	0	0	0	++

0 = no correlation   + = slight correlation, $R^2 > 0,5$ ++ = rather strong correlation, $R^2 > 0,8$

According to these results, it seems that the traditional cetane number measurement describes fairly well the real combustion properties of conventional and alternative diesel fuels in both heavy-duty engines tested. On the other hand, better correlations were observed for the hydrocarbon fuels than with alternative fuels. There might be some benefit for advanced heavy-duty engines in developing better cetane number measurement. The advanced Audi 1.9 TDI engine seemed to be less sensitive to cetane number, both with hydrocarbon and alternative fuels, although there were differences in emissions between the fuel qualities.

The differences between the ignition properties of the test fuels were most prominent at low engine loads. If the load was high, combustion properties of the all fuels studied were similar. At high loads the temperature of the cylinder is so high that even poor ignition property fuels tend to autoignite at an optimum ignition delay.

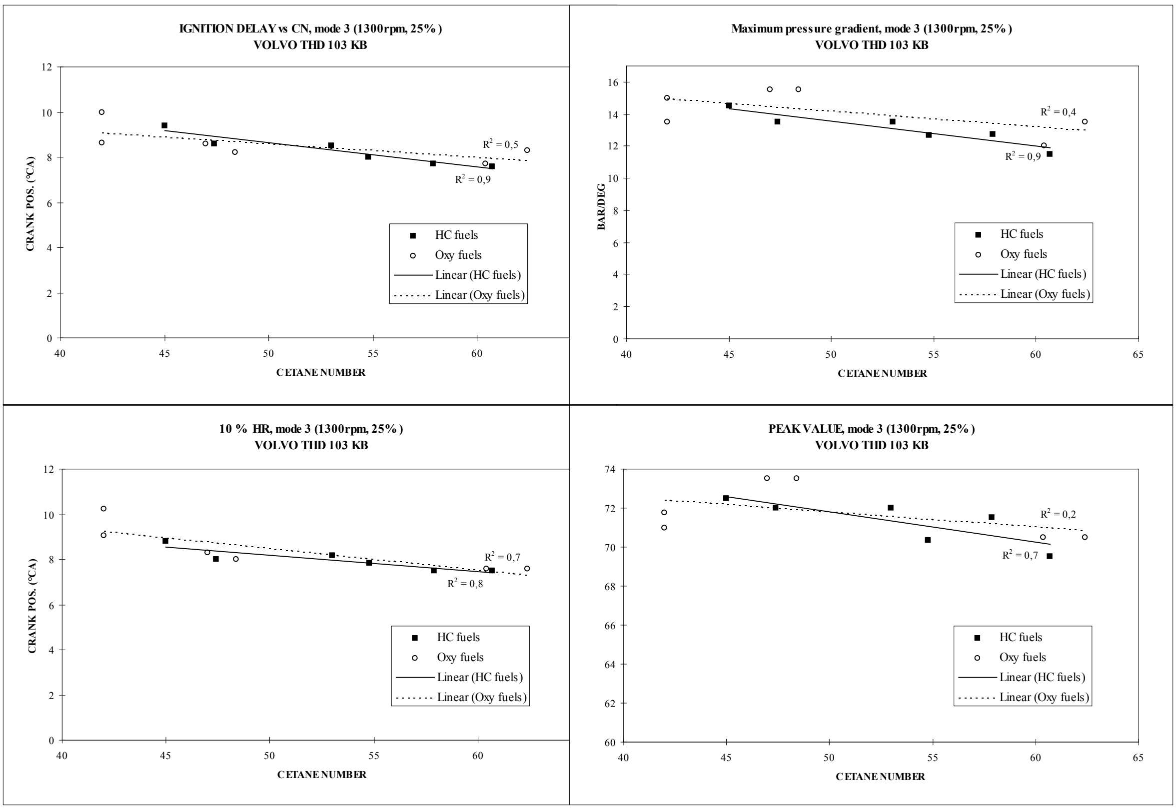


Figure 27. Correlations with the cetane number, VOLVO THD 103 KB.

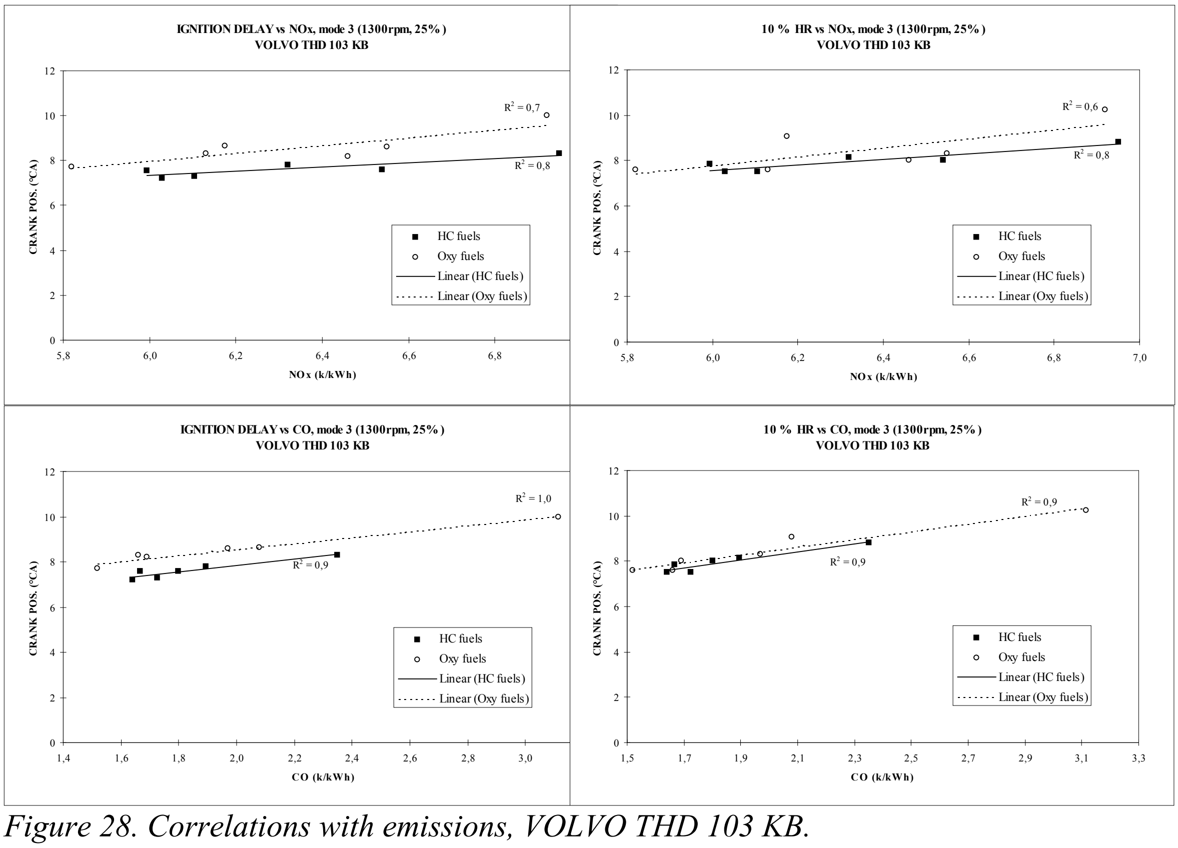


Figure 28. Correlations with emissions, VOLVO THD 103 KB.

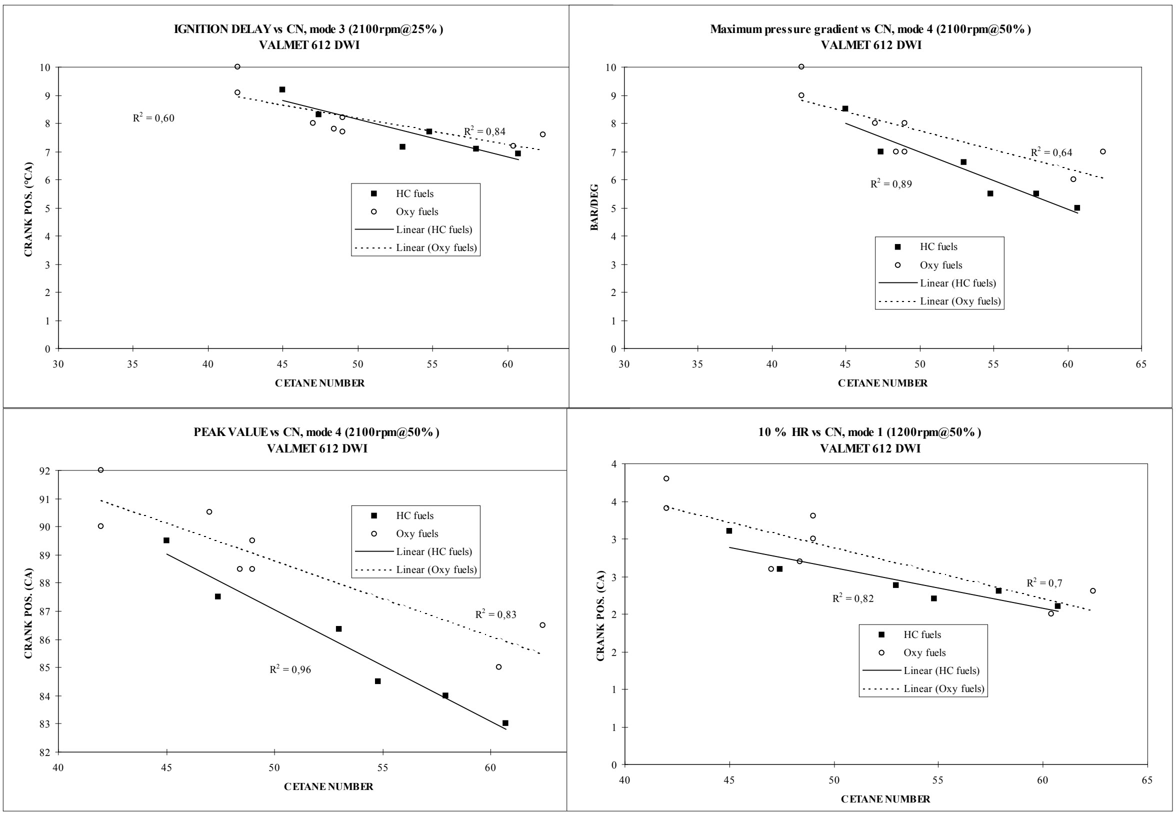


Figure 29. Correlations with cetane number, VALMET 612 DWI.

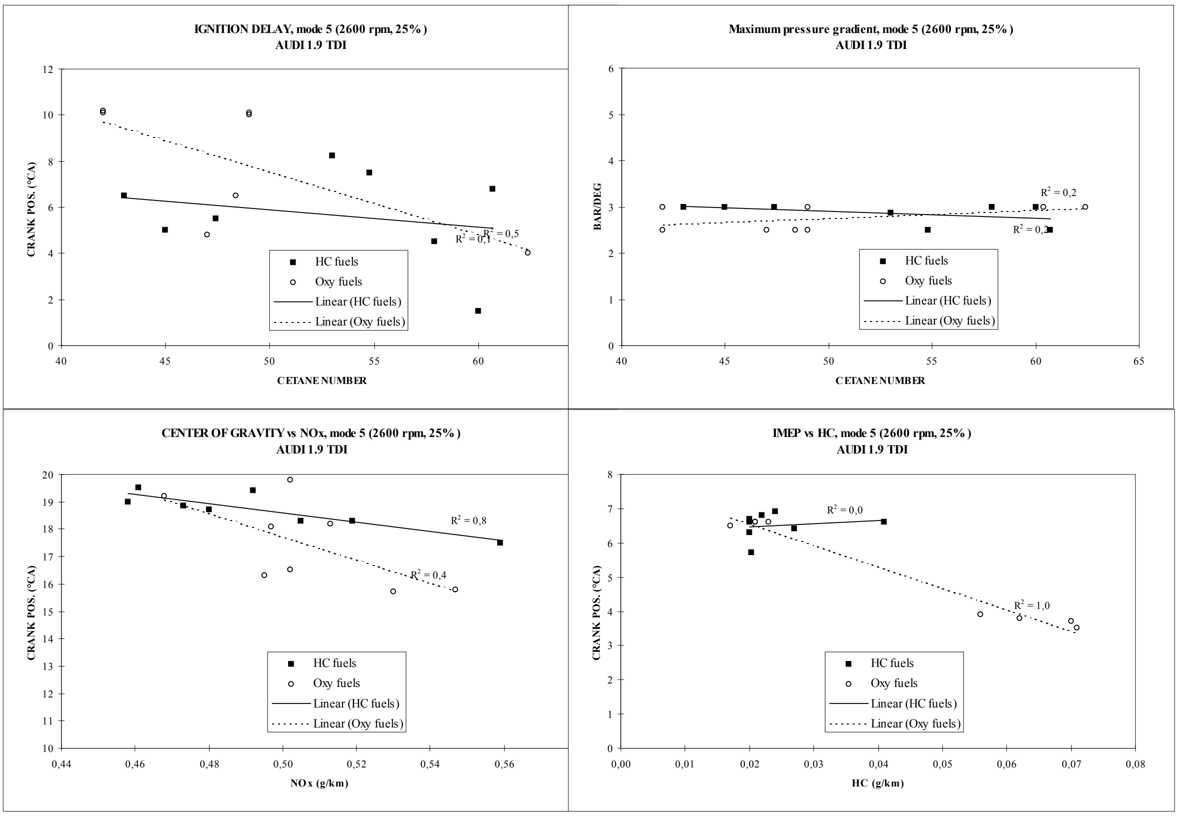


*Figure 30. **No** correlations observed for Audi 1.9 TDI. Despite the fairly high correlation factor values, the correlations are insignificant (the data is divided into two groups).*

PART TWO:
Emissions, combustion properties and startability at low temperatures

8 Startability tests with the Valmet 620 engine

8.1 Test program and procedures

The CEC and RME20 fuels with poor low temperature properties were selected for determining the lowest real-life cold startability temperatures and to study the effect of additives on RME containing fuel. These fuels were run with and without a cold improver package.

The laboratory test results of the fuels were presented in chapter 3. The cold properties of the test fuels are also presented in *figure 32*. The tests were carried out in a climatic test cell with a medium heavy-duty Valmet 620 engine.

Engine characteristics are as follows:

Identification	*VALMET 620 DS, vertical farm tractor engine* *turbo-charged, direct-injection*
Pump	*rotary-type pump*
Displacement	*6.6 litres*
Cylinders	*6*
Power output	*130 kW / 2400 rpm, 630 Nm / 1500 rpm*

The engine is equipped with flame-type inlet air heater to facilitate cold starting, but this device was not used.

The engine was installed in the cold test cell in the same dynamometer as described for the Valmet 612 DWI engine in chapter 5. The same equipment was also used for emission measurements. In addition, also exhaust opacity was measured (Smokemeter DST 200 by Electra Control).

The procedure used for cold startability tests was an in-house test planned together with the engine manufacturer. However, the basic principles of the test were similar to the CEC M-11-T-89 test method for cold weather performance test procedure for diesel vehicles. The CEC M-11-T-89 method lists three different types of tests: startability, operability (filter plugging) and driveability. The tests at VTT were carried out for startability.

The lowest startability temperature was screened by decreasing the temperature of the test cell by steps of 6 °C, until the engine did not start. After that, the test cell temperature was elevated by steps of 3 °C, until the engine started again. Only one cold start was carried out per day. Thus the stabilisation time of temperature was some 24 hours.

A separate canister was used for the fuel back flow to prevent heating of the fuel. This was done despite the fact that no actual cold operability tests (filter plugging) were carried out.

Starting was done with full throttle, and cranking was continued until the engine speed reached a value of 600 rpm. If the engine did not start in 30 seconds, starting was tried again after 10 seconds waiting, but not more than three times.

After the engine had started and run out, the engine speed was changed to 1 800 rpm, and the test was stopped after an idle period of 3 minutes.

After a successful start test, the engine was warmed up by running it for 200 seconds with 1 500 rpm/100 Nm, then for 200 - 300 seconds with 200 Nm torque and finally with 1800 rpm/300 Nm torque. Warming up of the engine in between the tests is necessary to secure repeatability. An example on engine speed and battery voltage during a test is shown in *figure 31*.

The engine was shut down when the temperature of oil was >65 °C, cooling water > 80 °C and exhaust gases > 330 °C.

Regulated exhaust emissions and opacity were measured during the cold start test and at room temperature.

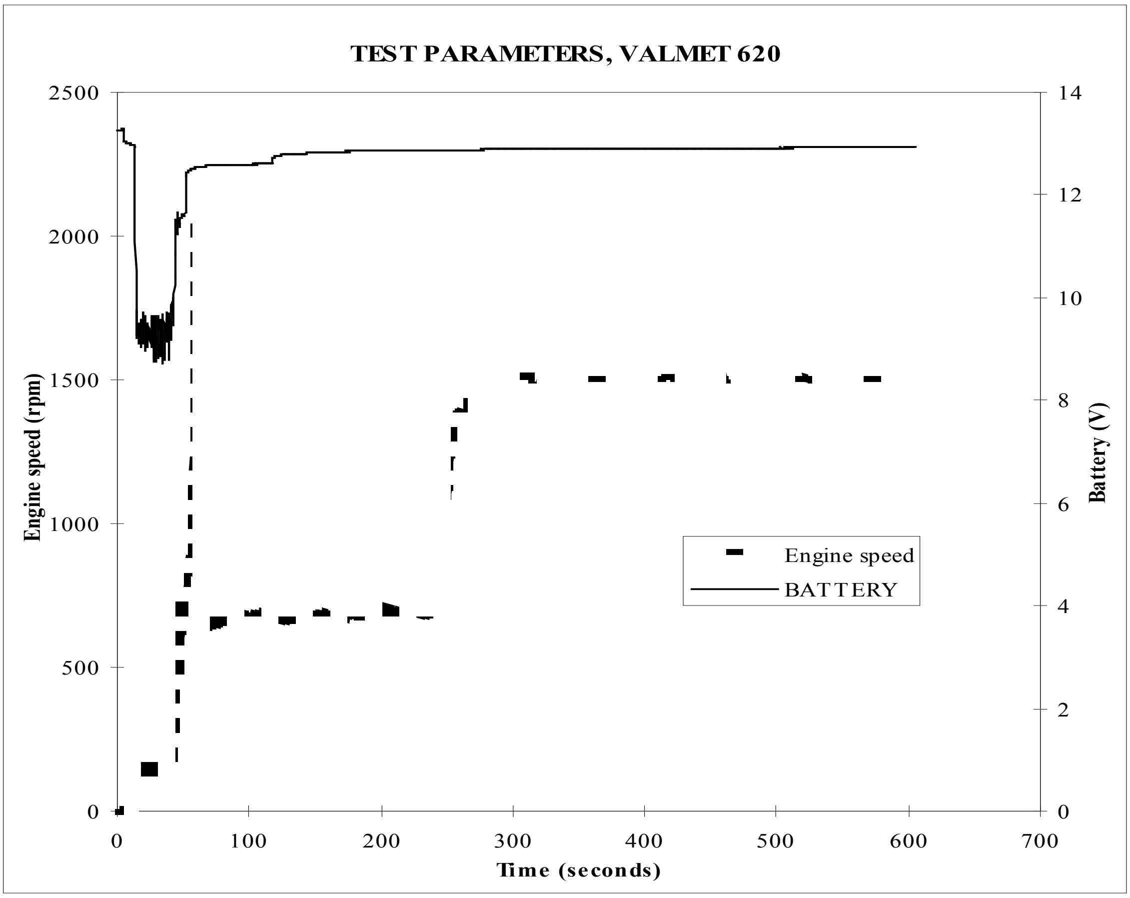


Figure 31. Engine speed and battery charge during the cold start test.

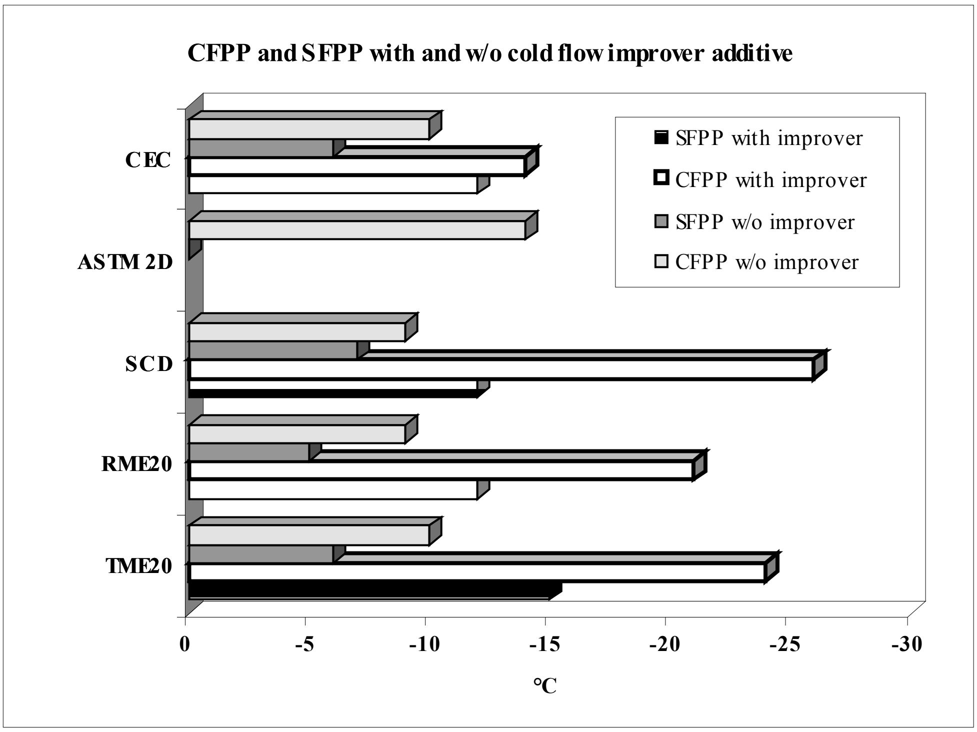


Figure 32. Cold properties of the test fuels with and without cold flow improvers.

8.2 The lowest starting temperatures

The lowest starting temperatures and the results of laboratory analysis are presented in *table 10*.

Several items influence on cold performance. One important item is the vehicle itself. Different vehicles have different fuel systems, tanks etc. Also several fuel properties influence on cold startability and operability: cloud point, pour point, CFPP, SFPP, distillation characteristics, cetane number, viscosity etc. A great number of wide studies have been made of the correlations between fuel properties and real low temperature operability limits for hydrocarbon diesel fuels. In this study, the laboratory analysis of cold properties and real cold startabilities of RME containg fuel was compared to the fuel, which was used as the base fuel of RME blend. Both fuels were tested with and without cold flow improvers.

The results obtained in this study are indicative, because the quality of base fuel and the characteristics of an engine influence a lot on the results. Now only one type of base fuel and engine were studied. Only cold properties of the fuels are discussed in this context, because there were no major differences between the test fuels e.g. in viscosity.

When RME was added to CEC fuel, it was observed that the results of the laboratory analysis of the cold properties stayed at the same level. However, the real starting temperature of RME blend was significantly worse than that of the base fuel.

When cold flow improver was added to the test fuels, the laboratory analysis data was similar for base fuel and RME blend, except for CFPP which gave very high response for RME blend. The real starting temperatures were at the same level for both fuels containing cold flow additive.

Altogether, it seems that the traditional laboratory analysis might give misleading results, if diesel fuel contains RME and especially when cold flow additive is used. However, this is the case also for several types of hydrocarbon fuels. The negative effect of RME on the real cold startability was avoided in these measurements, when the cold flow additive was used. However, this applies only to the cold startability, because no operability tests were included in this work.

Table 10. The lowest starting temperatures of the CEC and RME20 fuels with and without a cold flow improver.

	Cloud point °C	**CFPP °C**	**SFPP °C**	**Real starting temperature, °C**
CEC	-5	-10	-6	**-12**
CEC+cfi	-7	-14	-12	**-15**
response to cfi	*1*	*4*	*6*	*3*
RME20	-5	-9	-5	**-8**
RME20+cfi	-6	-21	-12	**-15**
response to cfi	*1*	*12*	*7*	*7*

8.3 The emission performance at the lowest starting temperatures

The HC concentrations and opacity results are presented in *figures 33* and *34*. The measurements were carried out at the lowest operability temperatures. Consequently, the fuels cannot be compared with each other.

The highest HC peak value and also highest level of HC after engine warm-up was measured for RME20 fuel with cfi at -15 °C. The lowest values were obtained for RME20 fuel at -8 °C. The HC concentrations were dependent on test temperature.

The opacity (white smoke) results of RME20 with cfi at -15 °C were highest. CEC+cfi at the same test temperature resulted in lower white smoke values. The opacities measured for CEC and RME20 followed the order of test temperature.

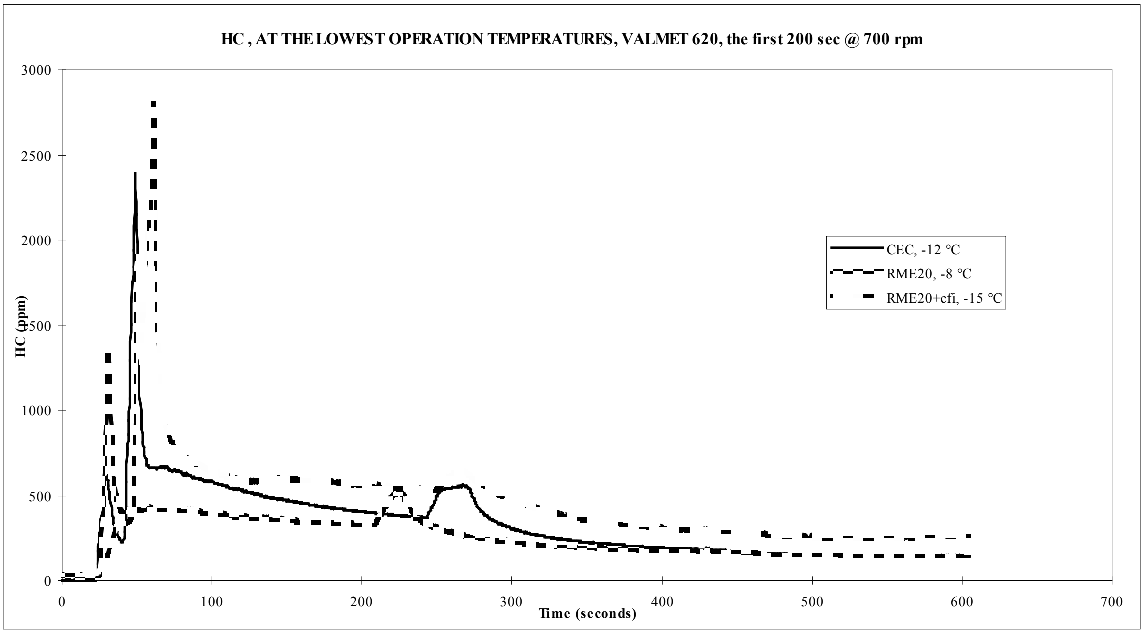


Figure 33. HC concentrations in the cold start test, Valmet 620.

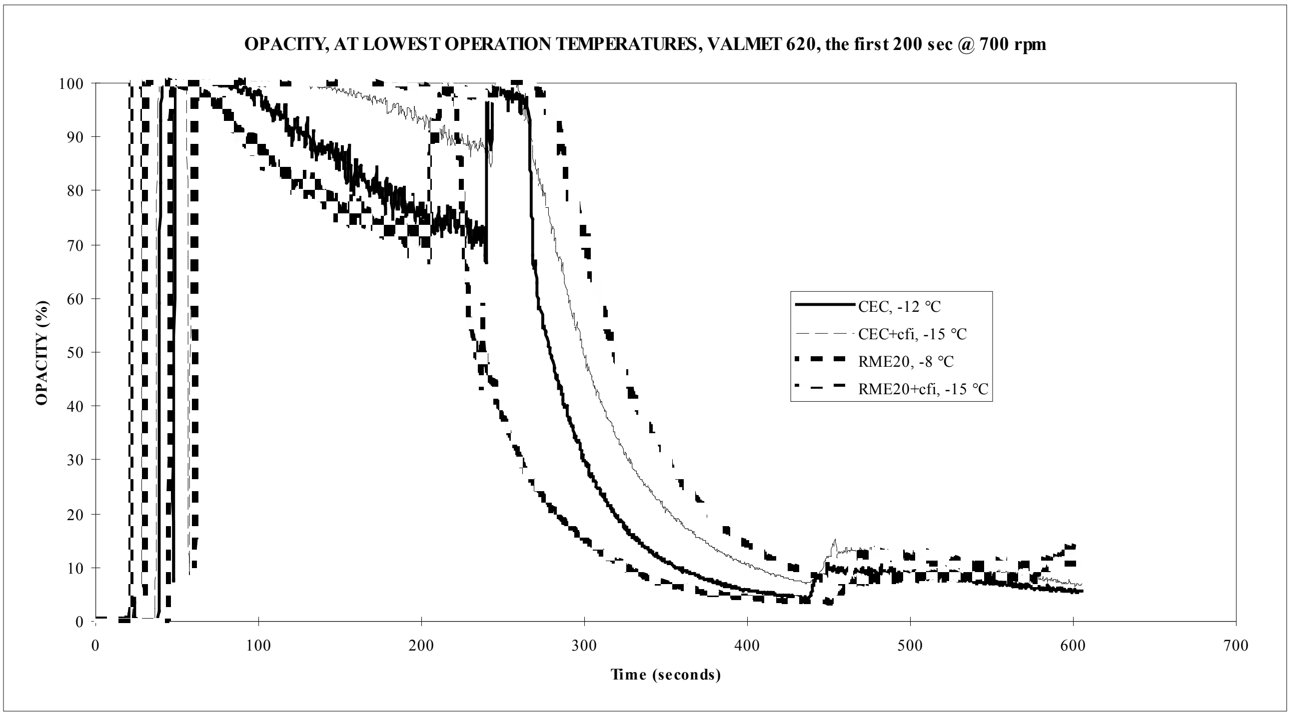


Figure 34. Opacity in the cold start test, Valmet 620.

9 Cold conditions performance tests with the Valmet 612 DWI engine

9.1 Test program and procedures

The cold conditions performance of selected test fuels (CEC, CEC+ci, RME20, RME20+ci, EtRE, EtRE+ci) was determined at -6 °C, which is suitable for all fuels according to cold start tests. The aim of the tests was to compare the cold conditions performance of the different fuels with each other at a certain temperature.

The engine used in the test was the Euro 2 emission level Valmet 612 DWI engine described in chapter 5. The test cell, dynamometer and emission measuring equipment were also the same.

The test program was divided into two parts:

1. Cold starting tests
2. Emission and combustion tests

Cold starting tests were carried out with a procedure similar to that described for the Valmet 620 engine in chapter 8.

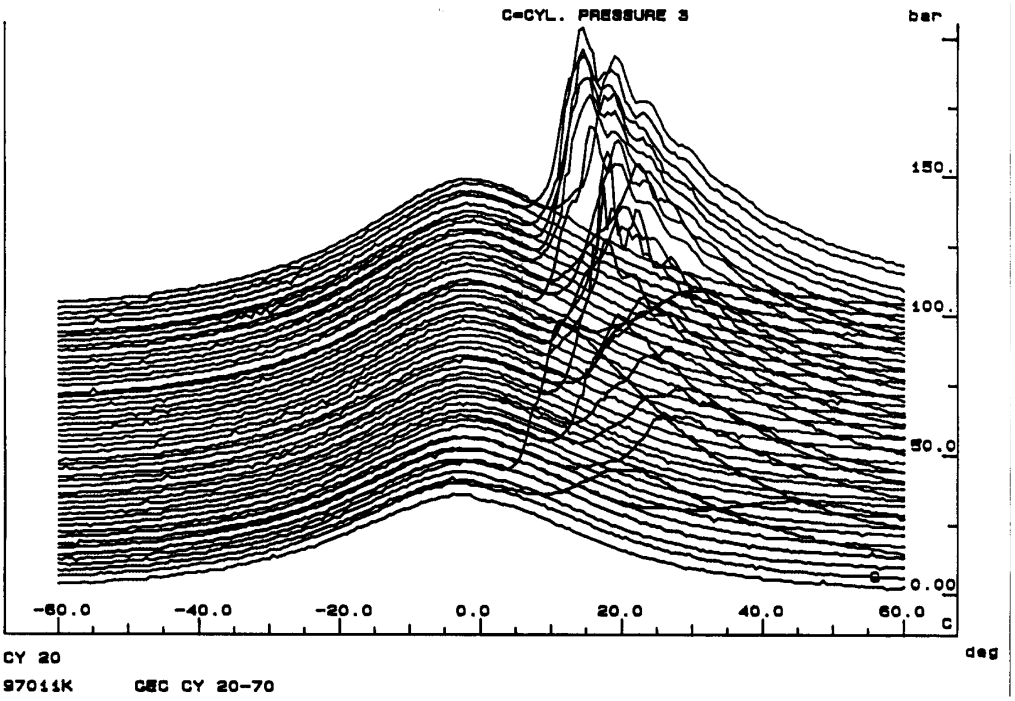
The emission and combustion tests were carried out directly after the cold start tests with the engine still cold. The measurements were carried out at the following loads:

1. intermediate speed, 25% load
2. intermediate speed, 50% load
3. rated speed, 25% load
4. rated speed, 50% load.

9.2 Cold starting at -6 °C

During the cold start tests at -6 °C, the cylinder pressure of some 50 consecutive working cycles was measured beginning from the start of cranking. This was in most cases sufficient to capture the start-up. There were clear differences between the test fuels. *Figures 35* and *36* show the cylinder pressure curves after start for the CEC, RME20, EtRE and EtRE+ci fuels.

Ignition occurs almost immediately after start of cranking with CEC fuel. Cylinder pressure curves for RME20 fuel are similar to CEC fuel. The EtRE fuel behaves quite differently. During the first 50 cycles after start of cranking ignition occurs only three times. When ignition improver is added to the EtRE fuel, ignition is significantly better than without additive, but worse than for CEC and RME20 fuels.



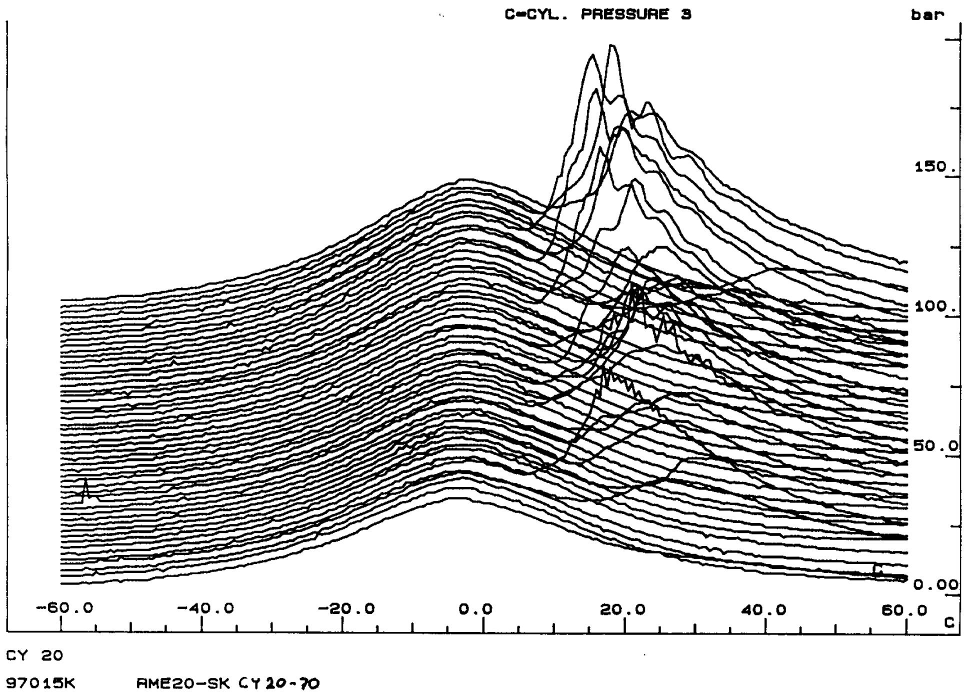
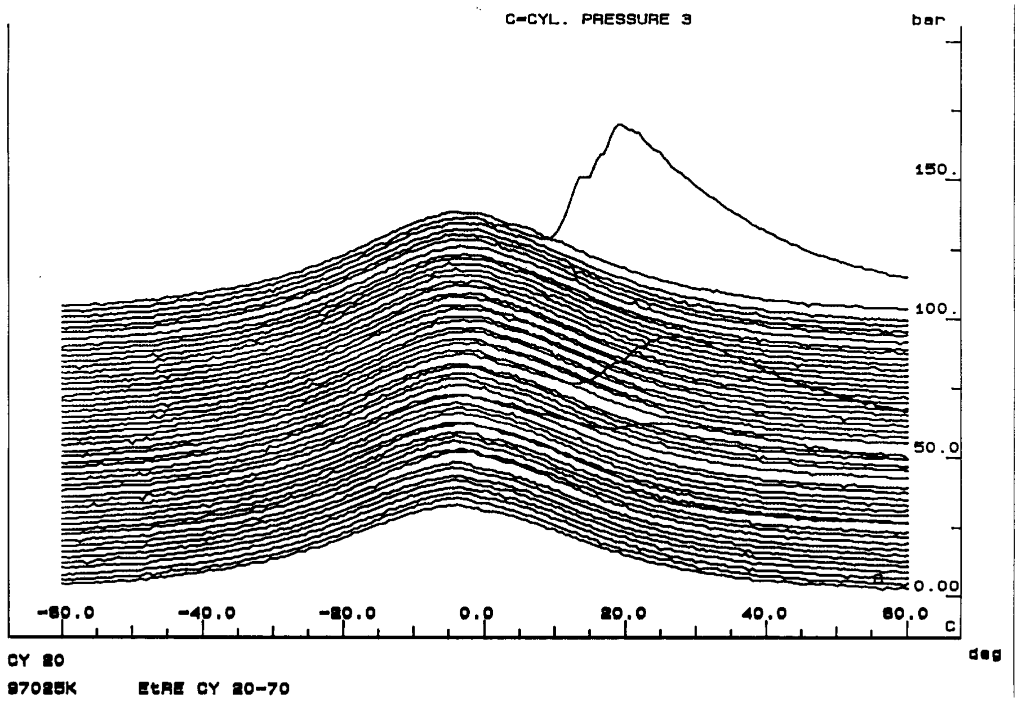


Figure 35. Cylinder pressure curves for the CEC and RME20+ci fuels during some 50 working cycles after the start of the engine at -6 °C.



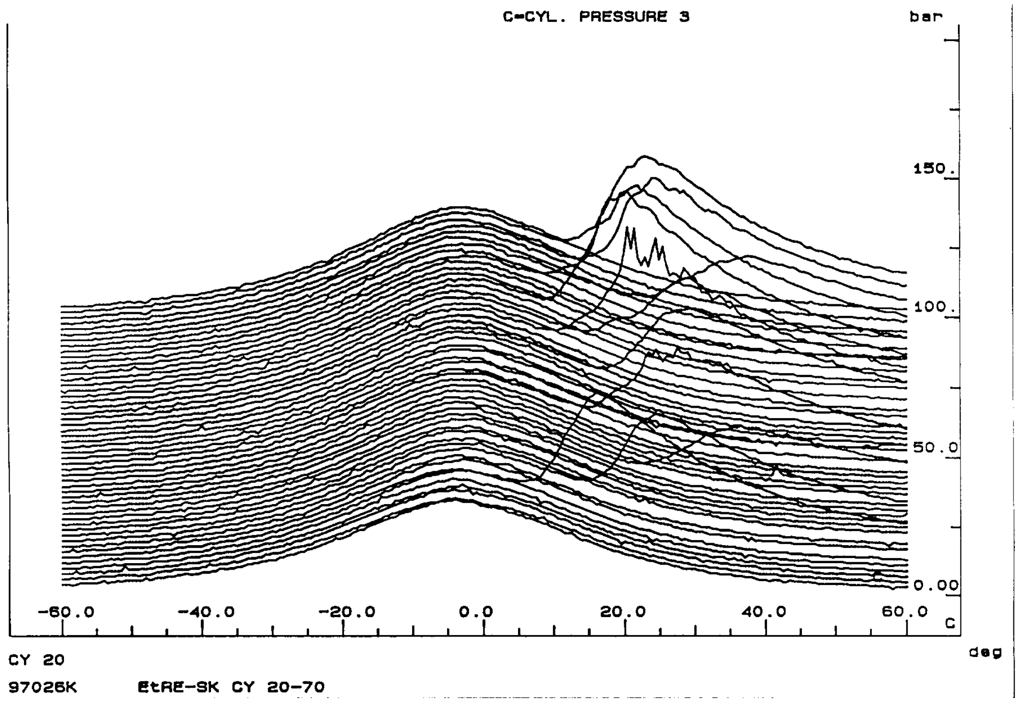


Figure 36. Cylinder pressure curves for the EtRE and EtRE+ci fuels during some 50 working cycles after the start of the engine at -6 °C.

No significant differences were observed in HC concentrations between the CEC and RME20 fuels (*figure 37*). HC concentrations with EtRE fuels were significantly higher than with CEC or RME20 fuels during the first 5 minutes. Cetane improver did not effect on HC concentrations.

The NO_x concentrations varied a lot with fuels (*figure 38*). The NO_x concentrations from the CEC fuels were about 1.5 times as high as for the RME20 fuels. EtRE fuels produced even higher NO_x concentrations than CEC fuels during the first 3 minutes, after that the NO_x concentrations with CEC and EtRE fuels were at the same level. Cetane improver did not effect the NO_x concentrations when the reliability of testing method is taken into account.

Smoke opacity was higher for the RME20 fuels than for the CEC fuels (*figure 39*) and the cetane improver reduced smoke opacity. Smoke opacity figures of EtRE fuels were most interesting. Opacity with EtRE fuel without cetane improver was the highest in the beginning of cold test, but was reduced sharply after three minutes. The cetane improver had a great influence on opacity with EtRE fuel: when cetane improver was added to EtRE fuel, this fuel had the lowest opacity of all fuels.

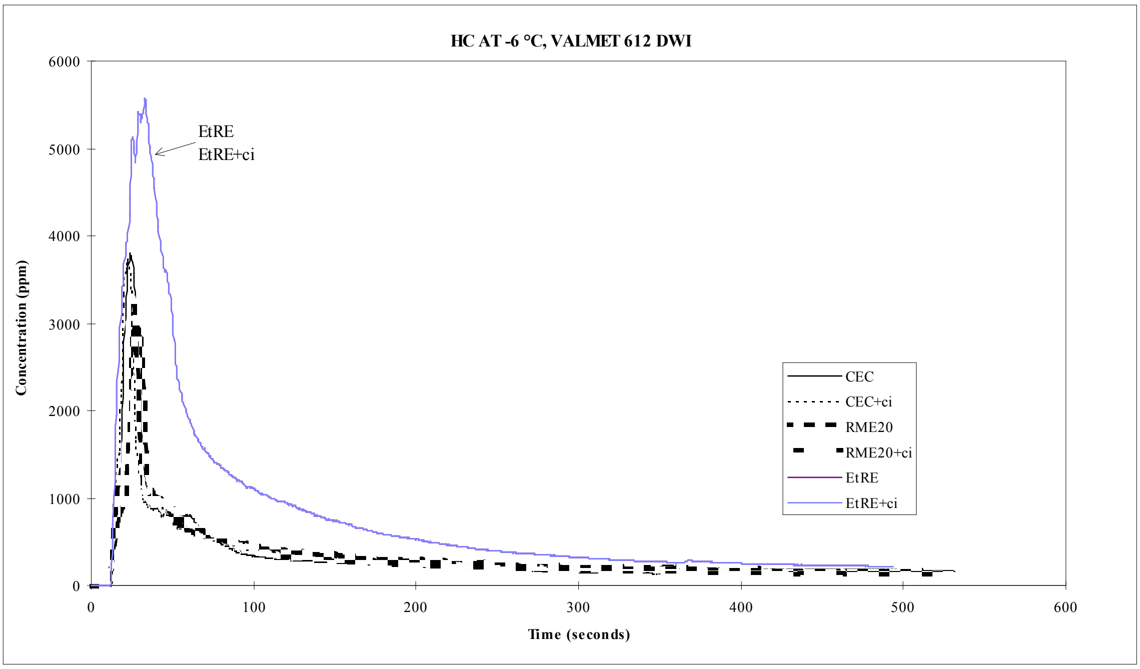


Figure 37. HC concentrations at -6 °C, Valmet 612 DWI.

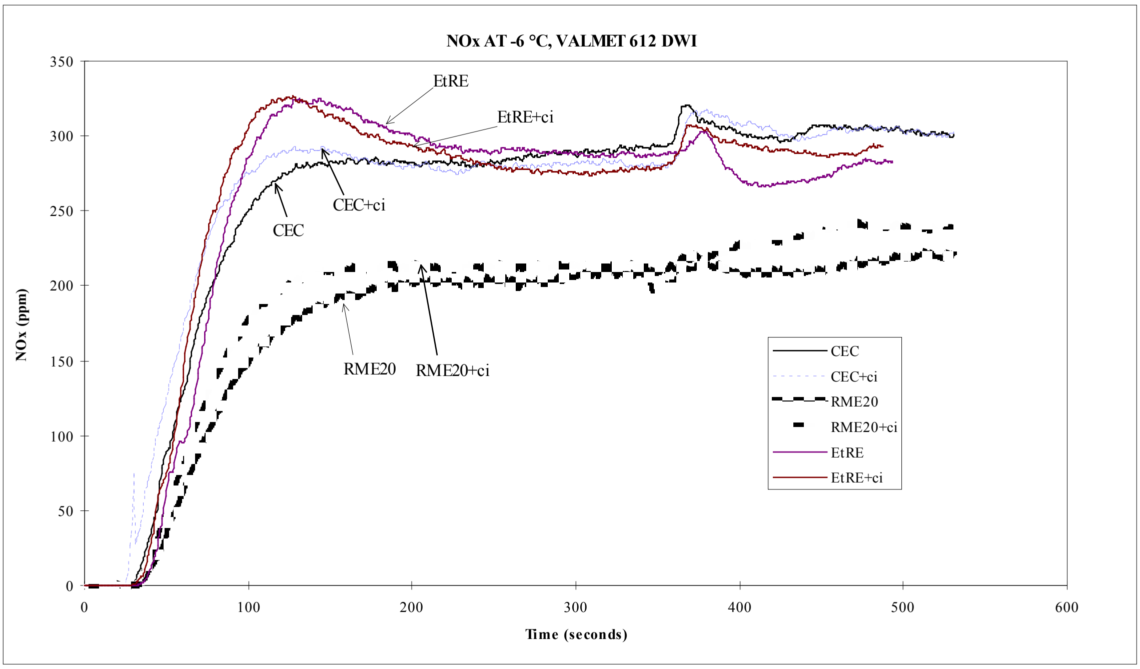


Figure 38. NO_x concentrations at -6 °C, Valmet 612 DWI.

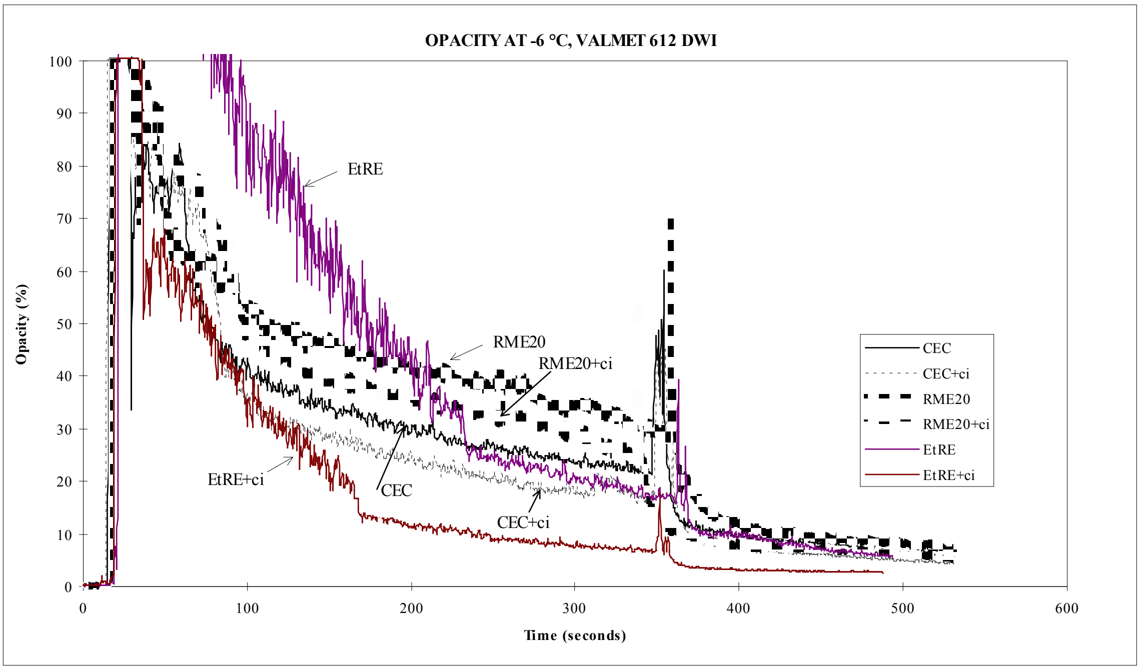


Figure 39. Opacity at -6 °C, Valmet 612 DWI.

9.3 Exhaust component concentrations with the cold engine under load at -6 °C

After the cold start test (chapter 8.2), the exhaust component concentrations of the VALMET 612 DWI engine were measured at intermediate and rated speeds, 50 and 25% loads.

The RME20 fuel gave in general the lowest exhaust concentrations (*figures 40* and *41*). Especially the NO_x concentrations were lowest for the RME20 fuel at all loads. No significant differences were observed between the CEC and EtRE fuels.

The cetane improver reduced CO and HC concentrations from all fuels, especially at 25% loads.

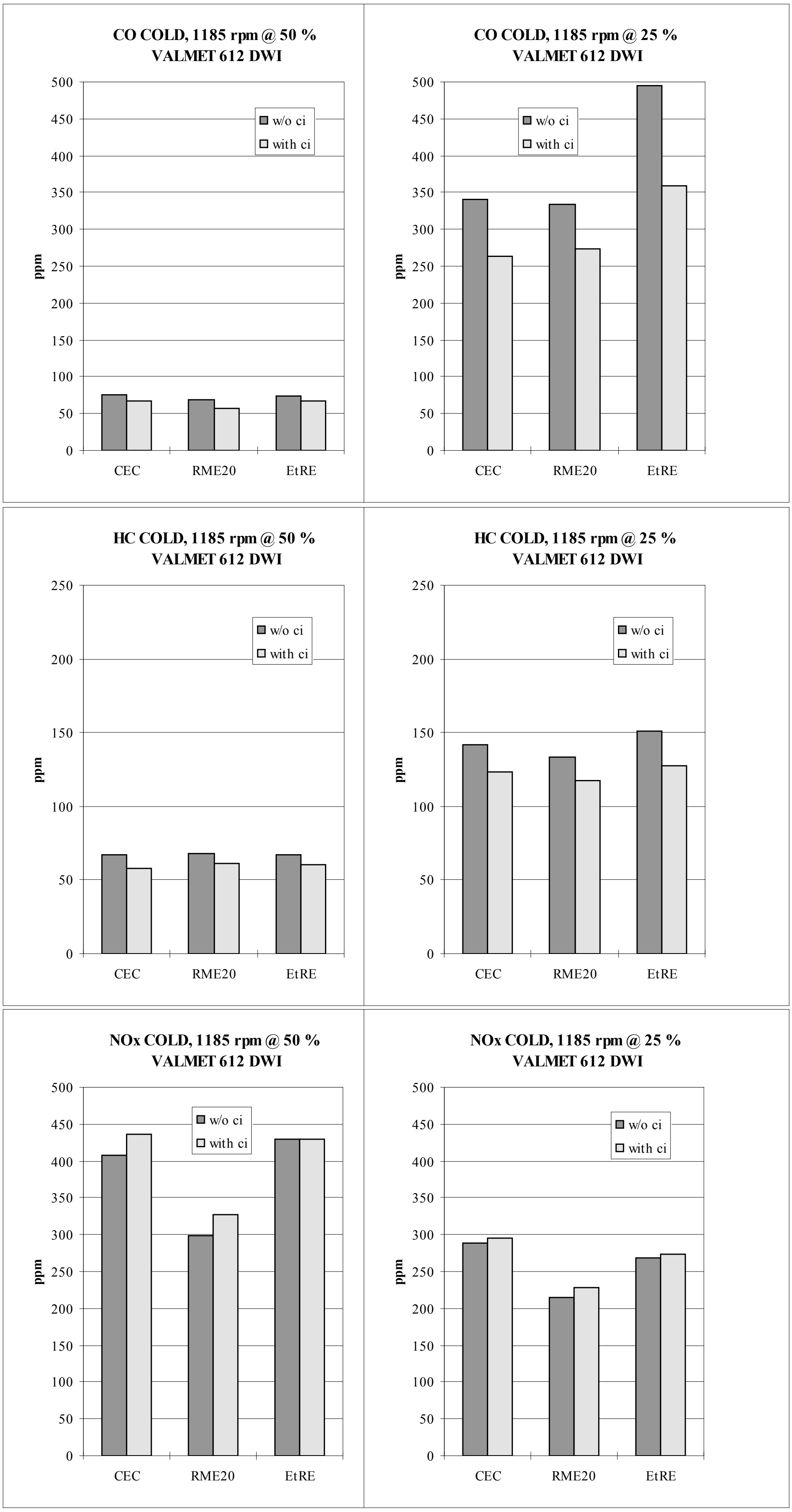


Figure 40. Exhaust concentrations with the VALMET 612 DWI engine (cold engine under load).

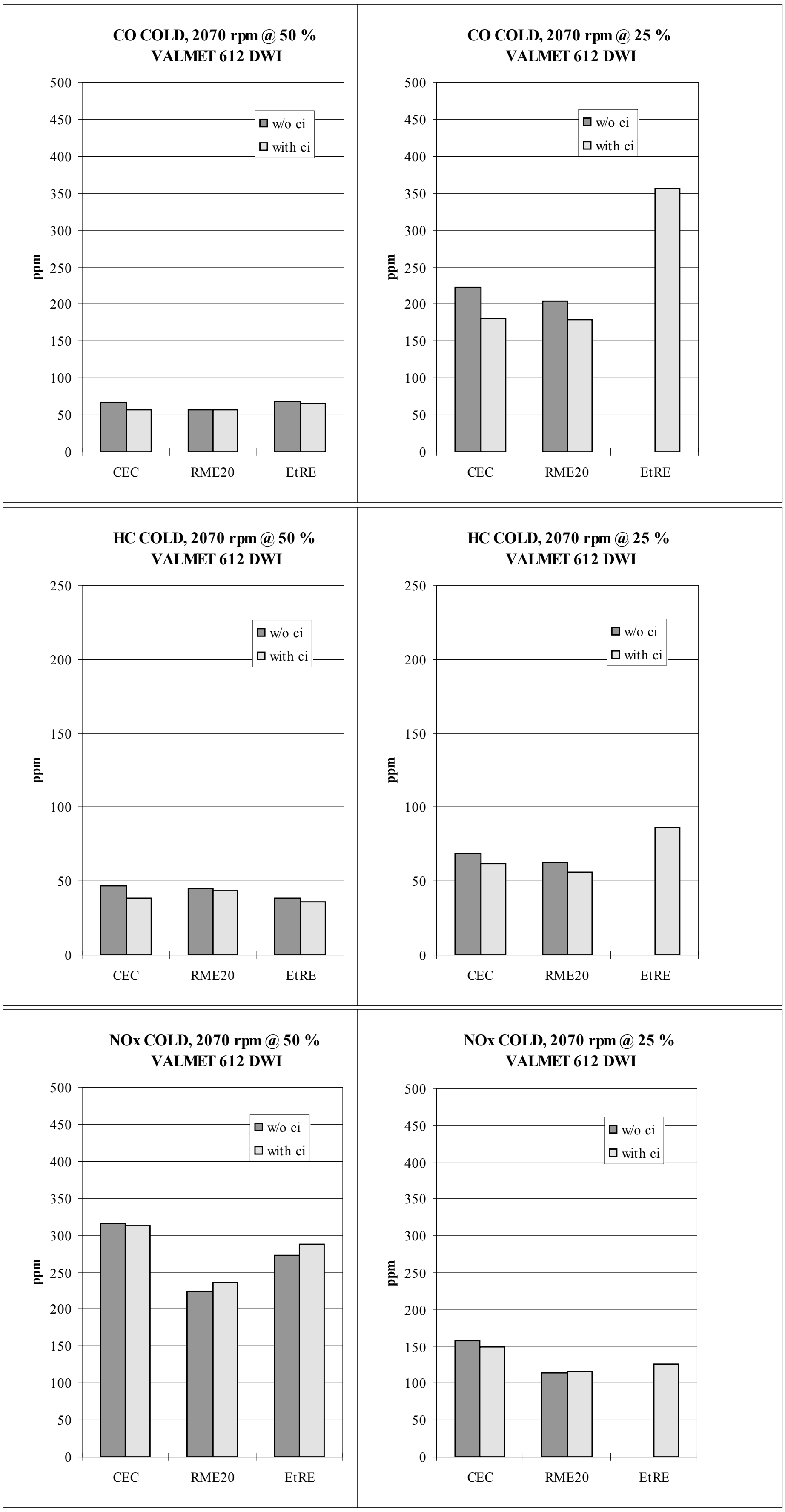


Figure 41. Exhaust concentrations with the VALMET 612 DWI engine (cold engine under load).

10 Cold emission tests with AUDI 1.9 TDI vehicle

10.1 Test program and procedures

The regulated emissions were measured with the Audi 1.9 TDI vehicle at -6 and +16 °C temperatures according to the US FTP75 test procedure. The vehicle and the equipment used for the tests are described in chapter 6. In addition to regulated emissions, opacity and formaldehyde emissions were measured.

The summary of the test program is presented in Table 11.

Table 11. Test program for cold emission tests with the Audi 1.9 TDI vehicle.

Fuel	**FTP -6 °C**	**FTP +16 °C**
CEC **CEC+ci** **RME20** **RME20+ci** **EtRE** **EtRE+ci**	**CO, HC, NOx** **formaldehyde** **opacity**	**CO, HC, NO_x** **formaldehyde** **opacity**

10.2 Results

The numeric results of the FTP measurements with the Audi 1.9 TDI engine are presented in Appendix 9. The emission reults are presented also in *figure 42*.

Regulated emissions

CO and HC emissions of Audi 1.9 TDI vehicle were low in general, even at -6 °C, where the CO emissions were twice as high as at +16 °C. Some small differences between the test fuels were observed. CO emissions were lower from the EtRE fuel than from the other fuels. The cetane improver seemed to reduce CO emissions by about 20% with all fuels. HC emission levels of the RME20 and EtRE fuels were slightly higher than that of the CEC fuel. The cetane improver reduced HC emissions considerably, at maximum close to 50% with RME20.

The NO_x emissions at -6 °C were of the same level as at +16 °C. No significant differences between the test fuels were observed.

The particulate emission was highest for the CEC fuels. Particulates were lower with RME20 fuel and especially with EtRE fuel. This is understandable, as the particulates of the RME20 and EtRE fuels are known to be “wet” and easily oxidised by the oxidation catalyst fitted to the vehicle.

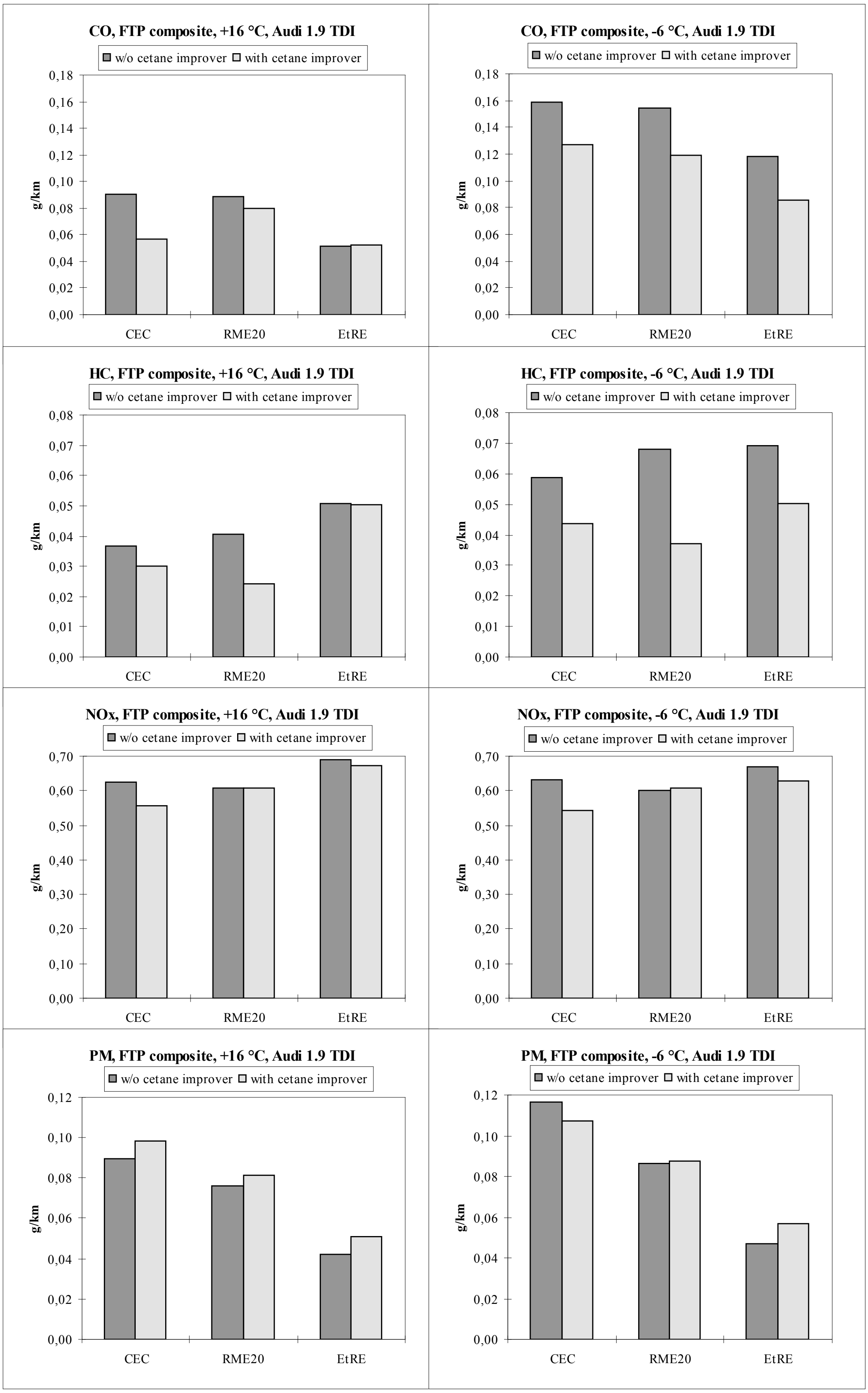


Figure 42. FTP results with Audi 1.9 TDI at +16 and -6 °C temperatures.

Formaldehyde

Differences in formaldehyde concentrations depending on the fuel were found only during the first 5 minutes of the FTP test. The peak formaldehyde concentrations at -6 °C were twice as high as at +16 °C. The peak values were highest for the CEC fuel at both test temperatures. The levels of the RME20 and EtRE fuels were at the same level.

The cetane improver reduced formaldehyde emissions in both test temperatures for all fuels. The highest reduction was observed for the CEC fuel at -6 °C (figure 43).

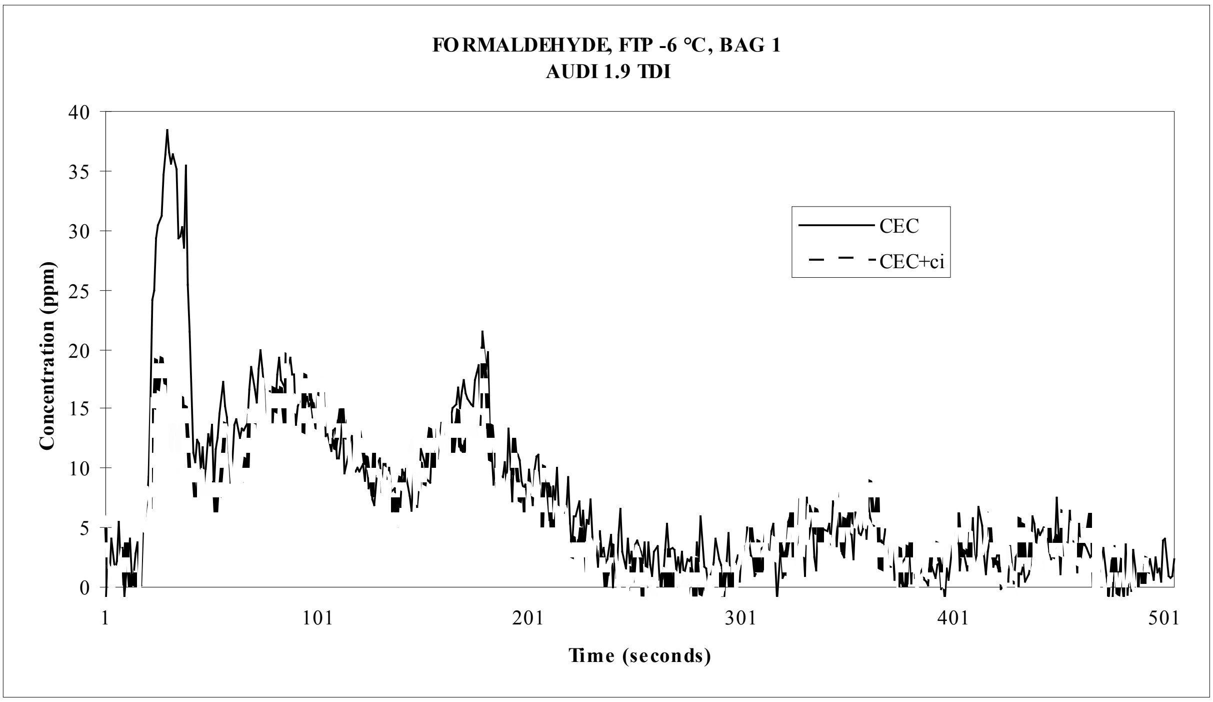


Figure 43. Formaldehyde concentrations in the first phase of the FTP test with the CEC fuel with and without the cetane improver at -6 °C. AUDI 1.9 TDI vehicle.

Opacity

The results of the opacity measurements are presented in tables 12 and 13. The opacities are calculated as areas from the height and width of the peaks in the chromatograms.

The opacity peaks after cold start at -6 °C were in general many times higher than at +16 °C. The opacities for the CEC fuel were highest at both temperatures. The EtRE fuel without the cetane improver did not produce any white smoke at all. The opacity seemed to rise slightly when the cetane improver was added to the test fuels at +16 °C. This was mainly due to the increase in peak width (longer period of time, where smoke occurs).

At -6 °C test temperature the addition of the cetane improver decreased white smoke for RME20 and EtRE. The opacity was highest with the CEC fuel, opacities with RME20 and EtRE fuels were at the same level.

Table 12. Opacities during FTP test at +16 °C. AUDI 1.9 TDI (one measurable peak)

	Height (mm)	**Width (mm)**	**Area (mm^2)**
CEC	29	3.5	**102**
CEC+ci, f7	23,5	7.0	**165**
RME20	18	3.0	**54**
RME20+ci, f10	21	6.0	**126**
EtRE	0	0	**0**
EtRE+ci	13	3.5	**46**

Table 13. Opacities during FTP test at -6 °C. AUDI 1.9 TDI.

	Peak 1 area (mm^2)	**Peak2 area (mm^2)**	**Others area (mm^2)**	**SUM (mm^2)**
CEC	92	233	35	**360**
CEC+ci, f7	90	248	19	**357**
RME20	78	144	15	**237**
RME20+ci, f10	72	120	6	**198**
EtRE	78	192	15	**285**
EtRE+ci	72	80	35	**187**

11 Summary

Many standardized tests for evaluating fuel characteristics have originally been designed for screening hydrocarbon products. In the case of fuels blended with new components or treated with additives, the conventional test methods may give misleading results. The objective of this task was to evaluate the correlation between the results of standardised testing and of the real-life serviceability of new diesel fuel qualities. The following characteristics were studied: combustion properties, properties affecting exhaust emissions, low-temperature performance and stability and diesel fuel lubricity.

The test fuel matrix comprised typical conventional hydrocarbon diesel fuels, low-emission hydrocarbon fuels, rapeseed and tall oil esters and ethanol-blended diesel fuels. The summary and abbreviations of the base tests fuels are as follows:

CEC	CEC reference fuel
ASTM2D	ASTM 2-D diesel fuel from North America
SCD	Scandinavian low-emission diesel fuel
RME20	CEC diesel fuel containing 20% rape seed methyl ester
TME20	CEC diesel fuel containing 20% tall oil methyl ester
EtOH15	diesel fuel emulsion containing 15% ethanol
EtRE	diesel fuel emulsion containing 10% ethanol and 4.3% RME

In addition cetane reference fuels CNref60 an CNref43 were tested with LD vehicle.

The base fuels were blended with a cetane improver additive and some fuels also with a cold flow improver additive.

The engines, vehicles and test procedures were as follows:

1. HD DI engine: VOLVO THD 103 KB, ECE R49, emissions + combustion properties
2. HD DI engine: VALMET 612 engine, emissions + combustion properties at 4 loads, cold start emissions
3. MHD DI engine: VALMET 620, in-house method, cold startability limit
4. LD DI vehicle: AUDI 1.9 TDI, steady-state tests at 5 loads for emissions + combustion properties, FTP tests (+16 and -6 °C)

Lubricity

The lubricity of all test fuels was acceptable (HFRR at 60 °C). The best lubricity results were achieved for the ester and ethanol blended fuels. RME clearly improved the lubricity of base fuels. The esters seem to act as lubricity improvers. However, based on only HFRR test, definitive conclusions of fuel performance cannot be drawn.

Combustion properties

The ignition properties of the fuel (cetane number) are most critical at low loads. If the cetane number is low, the ignition delay increases and there is a lot of fuel in the cylinder at the point of ignition. This may lead to a very fast combustion process, which may also be manifested as diesel “knocking”. Delayed ignition with following rapid combustion usually lead to higher emissions and noise.

For the heavy-duty VOLVO engine the ignition delay was longest and the duration of combustion shortest with the ethanol and low-cetane fuels. The effect of cetane improver was clear, the ignition delay was shorter and the combustion process more smooth when the cetane improver was used.

The same was observed for the HD VALMET 612 engine, although the combustion process was much more rough than in the VOLVO engine. The ignition delay was long in the VALMET engine in general, and the actual combustion process was rapid. In the Valmet engine, the start of injection and the location of center of gravity of combustion were retarded with the ethanol fuels. It was clearly seen that the ignition delay was shorter and the maximum cylinder pressure gradient occurred earlier with the fuels with the cetane improver, i.e., the combustion process was more smooth.

The tests with the Audi vehicle also indicated that the ignition delay was longer with the ethanol fuels than with the other fuels, and that ethanol blends after ignition burn very rapidly resulting in short duration of combustion. The effect of the cetane improver was not as clear as in the heavy-duty tests. However, some fuels, especially the ester-blended ones, having a very high response to the cetane improver, seemed to have a somewhat shorter ignition delay with the cetane improver additive than without it.

Correlation analysis (linear regression) was used to study which parameters affect combustion properties with the hydrocarbon fuels and the alternative fuels. The correlations varied for some parameters at different loads. As the light loads are most critical for the ignition process, they were given the main attention.

With the VOLVO heavy-duty engine the correlations of the cetane number with the ignition delay, the maximum cylinder pressure gradient and the heat release values were rather strong both for the hydrocarbon and alternative fuels. The correlations observed for the VALMET 612 DWI engine were very similar to those of the VOLVO engine. Several strong correlations between the cetane number and combustion properties were found both for the hydrocarbon and alternative fuels. The cetane number did not correlate with the combustion parameters of Audi TDI even with the hydrocarbon fuels, which might be due to the complex advanced technology of Audi.

According to these results, it seems that the conventional cetane number measurement describes fairly well the real combustion properties of alternative diesel fuels with heavy-duty engines under low-load conditions. However, the best correlations were found with hydrocarbon fuels. The advanced Audi 1.9 TDI engine seemed to be less sensitive to the cetane number, both with the hydrocarbon and alternative fuels, although there were differences in emissions between the fuel qualities. The CFR test tends to overestimate the effect of ignition improver additive for some fuels, especially those blended with esters.

Emissions

The highest HC and CO emissions from both heavy-duty engines (VOLVO, VALMET 612) were measured for the ethanol containing fuels and the ASTM2D fuel. The differences in HC and CO emissions between CEC, SCD and ester blended fuels were small. The difference between the HC emissions of the ethanol blends and the CEC fuel was seen only at low loads. Addition of RME to the ethanol blend decreased the HC emission significantly. The ethanol fuels gave the highest HC emissions also with the light-duty Audi vehicle both in the steady-state and the FTP tests. The HC and CO emissions were reduced in general when cetane improver was added.

With the heavy-duty VOLVO engine the NO_x emissions were some 35% lower with EtOH15 and EtRE than with the other fuels. This was not observed with the other heavy-duty engine, and neither did the ethanol fuels reduce NO_x emissions of the Audi vehicle when compared to CEC fuel. Ester blended fuels gave higher higher NO_x emissions than CEC fuel with VOLVO engine, but not with Valmet engine or Audi vehicle. The effect of fuel in this respect seem to be dependent on engine technology.

The particulates were measured with Volvo engine and Audi vehicle. Particulates were by far lowest with ethanol emulsion fuels. The Finnish low-emission hydrocarbon fuel, SCD and RME20, also gave a reduction in particulates compared with the CEC fuel.

Bosch smoke values were low for all fuels with Volvo engine. The lowest smoke values were observed for ethanol emulsion fuels at all loads. At high loads no other significant differences were observed between the fuels. At low loads the Bosch smoke increased with increasing cetane numbers (also when the cetane improver was added). Possibly the combustion process is not complete with low-cetane fuels and hence leads to “wet” particulates when black smoke decreases.

Smoke opacity at -6 °C with Valmet engine was high with EtRE without cetane improver, but lowest when cetane improver was added to fuel. The smoke opacity of the RME20 fuels was higher than that of the CEC fuels. With Audi vehicle at -6 °C the CEC fuel gave the highest opacity, RME20 and ethanol emulsion fuels were at the same level. With both engine technologies the cetane improver clearly reduced smoke opacity.

FTP tests with Audi 1.9 TDI at +16 and -6 °C showed that test temperature did not effect significantly the level of regulated emissions. The most significant difference between the test fuels was observed for particulate emission, which was the lowest with EtRE fuel at both test temperatures. Adding cetane improver to CEC, RME20 and EtRE fuels reduced CO and HC emissions at -6 °C test temperature.

Cold startability

The results obtained in this study for cold startability are indicative, because the quality of base fuel and the characteristics of an engine influence a lot on the results. Now only one type of base fuel and engine were studied.

When RME was added to CEC fuel, it was observed that the results of the laboratory analysis of the cold properties stayed at the same level. However, the real starting temperature of RME blend was worse than that of the base fuel.

When cold flow improver was added to the test fuels, the laboratory analysis data was similar for base fuel and RME blend, except for CFPP which gave very high response for RME blend. The real starting temperatures were at the same level for both fuels containing cold flow additive. The negative effect of RME on the real cold startability was avoided in these measurements, when the cold flow additive was used. However, this applies only to the cold startability, because no operability tests were included in this work.

The HD VALMET 612 engine was used to study combustion properties at low temperature. Ignition occurred almost immediately after start of cranking with the CEC and RME20 fuels. The EtRE fuel had much worse startability. During the first 50 cycles after start of cranking ignition occurred only three times. When the ignition improver was added to the EtRE fuel, ignition improved significantly.

Overall conclusions of this research work were as follows:

Traditional cetane number measurement:

* Describes well ignition delay of heavy-duty engine at low and medium loads, but is more suitable for hydrocarbon fuels than for alternative diesel fuels.
* Does not describe combustion process with advanced light-duty vehicles.
* Cetane reference fuels do not function propertly in advanced engines.
* Overestimates the effect of cetane improvers, especially for biodiesels.
* Correlates with cold startability for some parameters.

Emissions:

* HC and CO are the highest for ethanol emulsion fuels, but may be reduced by adding RME. Cetane improver reduces HC and CO emissions in general.
* NO_x emissions are lowest for ethanol fuels, but the effect will vary with engine technology.
* Particulate matter emissions are lowest with ethanol fuels and Finnish low emission fuel. RME20 gives particulate emission benefits, if oxidation catalyst is used.
* The cetane improver reduces smoke opacity.

Lubricity, cold properties:

* Esters act as effective lubricity improvers according to HFRR tests.
* Cold startability of RME blend can be improved with cold flow additives.
* Ignition of EtRE fuel improves significantly when the ignition improver is used.

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4. Aakko, P., Lappi, M., Laurikko, J. & Nylund, N.-O. Experiences in analyzing the exhaust gas emissions of vehicles using fast on-line FTIR. Nordic Seminar on Gas Analysis in Combustion, Tampere, 4 - 5 October 1994.

5. Brown, G. I. & Gaskill, G. P. Enchanced diesel fuel low temperature operability. Erdöl und Kohle, Bd. 43 5, Mai 1990, p. 196 - 205.

Fuel property		CEC F1	ASTM 2D F2	SCD F3	RME20 F4	TME20 F5	EtOH15 F6	EtRE F18
Density, 15 °C	kg/l	0,841	0,847	0,826	0,850	0,851	0,817	0,820
Viscosity, 40 °C	mm2/s	3,0	2,4	2,7	3,3	3,2	3,1	2,4
HFRR, 60 °C		385	391	306	172	282	226	182
Sulphur	wt-%	0,12	0,038	<0,002	0,081	0,081	<0,002	<0,002
Flash point	°C	80	63	86	83	77	na	na
TAN	mgKOH/g	0,02						
Cu-corrosion		1a						
Ash content	wt-%	<0,01						
Water	wt-%	0,006						
Stability	mg/100ml	<0,1						
Distillation								
IBP	°C		157	202	209	206	*	*
5 %	°C		194	229	234	236	*	*
10 %	°C		206	235	244	244	*	*
20 %	°C		220	242	254	254	*	*
30 %	°C		233	248	263	264	*	*
40 %	°C		244	254	274	274	*	*
50 %	°C	269	256	261	286	287	*	*
60 %	°C		268	268	301	302	*	*
70 %	°C		281	279	317	319	*	*
80 %	°C		297	296	331	332	*	*
90 %	°C	338	319	235	342	343	*	*
95 %	°C		339	349	351	354	*	*
FBP	°C	362	353	362	358	358	*	*
Recovery	°C		97,5	98	98	98	*	*
Residue	°C		1,5	1,5	1	1,5	*	*
Loss	°C		1	0,5	1	0,5	*	*
Cetane number	w/o ci	53,0	45,0	54,8	48,4	47,0	42,6/34,2	48,8/41,2
	with ci	57,9	47,4	60,7	60,4	62,4	45,5/49,8	-/48,5
	response	4,9	2,4	5,9	12	15,4	3-16	7
Cloud point, °C	w/o cfi	-5	-14	-8	-5	-7	**	**
	with cfi	-7		-9	-6	-8		
CFPP, °C	w/o cfi	-10	-14	-9	-9	-10	-39	< -39
	with cfi	-14		-26	-21	-24		
SFPP, °C	w/o cfi	-6	-	-7	-5	-6	-	
	with cfi	-12		-12	-12	-15		

*) could not be distilled because of foam formation

**) analysis method is not suitable for emulsions

AVERAGE VALUES VOLVO THD 103 KB

FUEL		HC g/kWh	CO g/kWh	NOx g/kWh	PARTICULATES g/kWh
Reference	DIKC 95/238	0,393	0,833	6,00	0,194
CEC	F1	0,418	0,870	6,13	0,219
ASTM2D	F2	0,478	0,965	6,32	0,209
SCD	F3	0,416	0,830	6,05	0,186
RME20	F4	0,409	0,860	6,45	0,200
TME20	F5	0,417	0,855	6,50	0,251
EtOH15	F6	0,579	1,275	5,38	0,136
CEC+ci	F7	0,430	0,805	6,17	0,224
ASTM2D+ci	F8	0,459	0,860	6,31	0,207
SCD+ci	F9	0,409	0,745	6,04	0,172
RME20+ci	F10	0,380	0,780	6,34	0,204
TME20+ci	F11	0,372	0,830	6,14	0,267
EtRE	F18	0,462	1,000	5,56	0,146

STANDARD DEVIATIONS, ABSOLUTE VALUES

FUEL		HC g/kWh	CO g/kWh	NOx g/kWh	PARTICULATES g/kWh
Reference	DIKC 95/238	0,0158	0,0094	0,227	0,0168
CEC	F1	0,0020	0,0100	0,027	0,0030
ASTM 2D	F2	0,0065	0,0050	0,007	0,0010
SCD	F3	0,0060	0,0100	0,043	0,0055
RME20	F4	0,0065	0,0100	0,020	0,0020
TME20	F5	0,0105	0,0150	0,034	0,0015
EtOH15	F6	0,0120	0,0050	0,079	0,0050
CEC+ci	F7	0,0010	0,0050	0,018	0,0040
ASTM2D+ci	F8	0,0005	0,0100	0,081	0,0015
SCD+ci	F9	0,0040	0,0450	0,007	0,0100
RME20+ci	F10	0,0155	0,0000	0,103	0,0000
TME20+ci	F11	0,0085	0,0100	0,037	0,0025
EtRE	F18	0,0045	0,0000	0,026	0,0030

STANDARD DEVIATIONS, %

FUEL		HC %	CO %	NOx %	PARTICULATES %
Reference	DIKC 95/238	4,0	1,1	3,8	8,6
CEC	F1	0,5	1,1	0,4	1,4
ASTM 2D	F2	1,4	0,5	0,1	0,5
SCD	F3	1,4	1,2	0,7	3,0
RME20	F4	1,6	1,2	0,3	1,0
TME20	F5	2,5	1,8	0,5	0,6
EtOH15	F6	2,1	0,4	1,5	3,7
CEC+ci	F7	0,2	0,6	0,3	1,8
ASTM2D+ci	F8	0,1	1,2	1,3	0,7
SCD+ci	F9	1,0	6,0	0,1	5,8
RME20+ci	F10	4,1	0,0	1,6	0,0
TME20+ci	F11	2,3	1,2	0,6	0,9
EtRE	F18	1,0	0,0	0,5	2,1
Maximum standard deviation		*4,1*	*6,0*	*3,8*	*8,6*

CHANGE-%	HC	CO	NOx	PARTICULATES
CEC->ASTM2D	14,2	10,9	3,1	-4,6
CEC->SCD	-0,5	-4,6	-1,3	-15,3
CEC->RME20	-2,3	-1,1	5,2	-8,7
CEC->TME20	-0,4	-1,7	6,1	14,4
CEC->EtOH15	38,5	46,6	-12,2	-37,9
CEC->EtRE	10,4	14,9	-9,3	-33,3
CEC->CEC+ci	2,9	-7,5	0,7	2,3
CEC->ASTM2D+ci	9,7	-1,1	3,0	-5,7
CEC->SCD+ci	-2,2	-14,4	-1,4	-21,5
CEC->RME20+ci	-9,2	-10,3	3,5	-6,8
CEC->TME20+ci	-11,1	-4,6	0,2	21,7
CEC->CEC+ci	2,9	-7,5	0,7	2,3
ASTM2D->ASTM2D+ci	-4,0	-10,9	-0,1	-1,2
SCD->SCD+ci	-1,7	-10,2	-0,1	-7,3
RME20->RME20+ci	-7,1	-9,3	-1,6	2,0
TME20->TME20+ci	-10,8	-2,9	-5,6	6,4

BOSCH SMOKE RESULTS, VOLVO THD 103 KB, ECE R49

AVERAGE VALUES

		Mode2	Mode3	Mode4	Mode5	Mode6	Mode8	Mode9	Mode10	Mode11	Mode12
Reference	DIKC 95/2	0,473	0,793	0,873	0,860	0,973	0,980	1,060	1,140	1,323	1,023
CEC	F1	0,4	0,8	0,83	0,855	0,86	1	1,17	1,13	1,335	0,89
ASTM2D	F2	0,28	0,805	0,775	0,86	0,96	1,005	1,18	1,165	1,275	0,3
SCD	F3	0,45	0,735	0,795	0,795	0,85	0,895	1,075	1,16	1,23	0,945
RME20	F4	0,38	0,63	0,705	0,6	0,775	0,835	0,975	0,99	1,085	0,775
TME20	F5	0,37	0,75	0,825	0,71	0,795	0,78	0,97	0,96	1,165	0,675
EtOH15	F6	0,055	0,26	0,385	0,38	0,545	0,505	0,55	0,505	0,395	0,065
CEC+ci	F7	0,575	0,86	0,86	0,79	0,89	0,92	1,1	1,17	1,435	1,285
ASTM2D+	F8	0,39	0,835	0,83	0,875	0,925	0,985	1,2	1,215	1,44	0,74
SCD+ci	F9	0,55	0,725	0,785	0,775	0,87	0,925	1,08	1,185	1,305	1,22
RME20+ci	F10	0,46	0,65	0,72	0,615	0,7	0,805	0,935	0,985	1,175	1,06
TME20+ci	F11	0,545	0,84	0,92	0,845	0,87	0,905	0,985	1,04	1,275	1,1
EtRE	F18	0,155	0,39	0,57	0,525	0,705	0,63	0,725	0,8	0,72	0,235

STANDARD DEVIATIONS, ABSOLUTE VALUES

		Mode2	Mode3	Mode4	Mode5	Mode6	Mode8	Mode9	Mode10	Mode11	Mode12
Reference	DIKC 95/2	0,057	0,057	0,113	0,094	0,086	0,057	0,016	0,024	0,025	0,012
CEC	F1	0,01	0,05	0,01	0,015	0,05	0,04	0,01	0,01	0,025	0,02
ASTM2D	F2	0,01	0,045	0,015	0	0,07	0,025	0,01	0,015	0,045	0,02
SCD	F3	0,01	0,005	0,045	0,015	0,01	0,045	0,005	0,02	0,04	0,005
RME20	F4	0	0,01	0,005	0,02	0,035	0,015	0,015	0,04	0,025	0,015
TME20	F5	0,01	0,05	0,025	0,01	0,035	0	0,03	0,02	0,015	0,015
EtOH15	F6	0,005	0	0,005	0,01	0,005	0,005	0,02	0,005	0,015	0,005
CEC+ci	F7	0,035	0,01	0,06	0,02	0,02	0,01	0,02	0,04	0,015	0,015
ASTM2D+	F8	0,02	0,005	0	0,005	0,035	0,015	0	0,005	0,01	0,01
SCD+ci	F9	0,01	0,005	0,035	0,025	0,03	0,035	0,03	0,025	0,005	0
RME20+ci	F10	0,01	0,01	0,01	0,015	0,02	0,015	0,025	0,025	0,005	0,01
TME20+ci	F11	0,015	0,01	0,03	0,015	0,03	0,055	0,015	0,05	0,025	0
EtRE	F18	0,005	0,01	0	0,005	0,015	0,03	0,025	0,03	0,02	0,015

STANDARD DEVIATIONS, %

		Mode2	Mode3	Mode4	Mode5	Mode6	Mode8	Mode9	Mode10	Mode11	Mode12
Reference	DIKC 95/2	12,1	7,2	12,9	10,9	8,8	5,8	1,5	2,1	1,9	1,2
CEC	F1	2,5	6,2	1,2	1,8	5,8	4,0	0,9	0,9	1,9	2,2
ASTM2D	F2	3,6	5,6	1,9	0,0	7,3	2,5	0,8	1,3	3,5	6,7
SCD	F3	2,2	0,7	5,7	1,9	1,2	5,0	0,5	1,7	3,3	0,5
RME20	F4	0,0	1,6	0,7	3,3	4,5	1,8	1,5	4,0	2,3	1,9
TME20	F5	2,7	6,7	3,0	1,4	4,4	0,0	3,1	2,1	1,3	2,2
EtOH15	F6	9,1	0,0	1,3	2,6	0,9	1,0	3,6	1,0	3,8	7,7
CEC+ci	F7	6,1	1,2	7,0	2,5	2,2	1,1	1,8	3,4	1,0	1,2
ASTM2D+	F8	5,1	0,6	0,0	0,6	3,8	1,5	0,0	0,4	0,7	1,4
SCD+ci	F9	1,8	0,7	4,5	3,2	3,4	3,8	2,8	2,1	0,4	0,0
RME20+ci	F10	2,2	1,5	1,4	2,4	2,9	1,9	2,7	2,5	0,4	0,9
TME20+ci	F11	2,8	1,2	3,3	1,8	3,4	6,1	1,5	4,8	2,0	0,0
EtRE	F18	3,2	2,6	0,0	1,0	2,1	4,8	3,4	3,7	2,8	6,4

COMBUSTION PROPERTIES, VOLVO THD 103 KB, Average results

ECE R49, mode	max. HR IM_10% 2	max. HR IM_25% 3	max. HR IM_50% 4	max. HR IM_75% 5	max. HR R_10% 12	max. HR R_25% 11	max. HR R_50% 10	max. HR R_75% 9	max. HR R_100% 6	max. HR R_100% 8
CEC	9,00	8,50	12,50	16,00	17,00	21,00	19,00	17,00	15,00	25,00
CEC+ci	8,00	8,00	10,00	12,00	16,00	20,00	18,00	22,00	14,00	22,00
ASTM2D	10,00	10,00	8,00	13,00	21,00	18,00	20,00	18,00	12,00	21,00
ASTM2D+ci	9,00	9,00	11,00	16,00	18,00	16,00	19,00	23,00	15,00	25,00
SCD	9,00	8,00	14,00	18,00	16,33	16,67	20,33	17,00	15,00	21,67
SCD+ci	8,00	8,00	10,00	12,00	15,00	14,00	18,00	17,00	17,00	30,00
RME20	9,00	8,00	14,00	16,00	17,00	21,00	19,00	17,00	18,00	20,00
RME20+ci	8,00	8,00	10,00	12,00	16,00	20,00	18,00	17,00	18,00	24,00
TME20	9,00	9,00	11,00	16,00	18,00	16,00	19,00	17,00	15,00	30,00
TME20+ci	9,00	8,00	7,00	19,00	16,00	15,00	18,00	17,00	15,00	24,00
EtOH15	12,00	11,00	10,00	14,00	25,50	22,00	23,00	22,50	16,00	17,00
EtRE	10,00	10,00	11,50	13,00	20,50	18,00	23,50	24,00	15,00	26,00
STDEVP-%, average	*0,0*	*1,2*	*12,0*	*1,6*	*1,5*	*2,8*	*4,7*	*2,2*	*0,0*	*4,0*

ECE R49, mode	5% HR IM_10% 2	5% HR IM_25% 3	5% HR IM_50% 4	5% HR IM_75% 5	5% HR R_10% 12	5% HR R_25% 11	5% HR R_50% 10	5% HR R_75% 9	5% HR R_100% 6	5% HR R_100% 8
AVERAGE VALUES										
CEC	8,25	7,75	7,30	6,80	14,40	13,45	12,10	11,45	7,60	10,80
CEC+ci	7,40	7,20	6,80	6,65	13,50	12,55	11,30	11,30	7,60	10,85
ASTM2D	9,20	8,40	7,80	6,70	17,20	15,40	13,50	12,10	7,00	10,90
ASTM2D+ci	8,20	7,60	7,10	6,70	15,30	14,00	12,40	11,70	7,80	10,40
SCD	7,83	7,50	7,07	6,50	14,27	13,27	12,17	11,43	7,90	11,13
SCD+ci	7,20	7,10	6,70	6,40	13,20	12,60	11,80	11,30	7,50	12,20
RME20	8,20	7,70	7,00	6,80	14,90	13,90	12,40	11,40	7,40	10,90
RME20+ci	7,60	7,20	6,70	6,80	13,80	13,10	11,80	11,20	7,90	11,20
TME20	8,40	8,10	7,40	6,70	15,60	13,90	12,50	11,60	7,30	10,70
TME20+ci	7,50	7,30	6,90	6,20	14,10	13,30	12,20	11,20	8,00	10,70
EtOH15	10,45	10,00	8,65	7,45	20,75	17,50	14,95	12,85	7,00	11,50
EtRE	9,00	8,65	7,65	6,95	17,00	15,25	13,25	12,10	7,95	11,25
STDEVP-%, average	*0,8*	*0,5*	*0,9*	*1,6*	*0,5*	*0,7*	*0,9*	*0,6*	*1,3*	*1,5*

ECE R49, mode	10% HR IM_10% 2	10% HR IM_25% 3	10% HR IM_50% 4	10% HR IM_75% 5	10% HR R_10% 12	10% HR R_25% 11	10% HR R_50% 10	10% HR R_75% 9	10% HR R_100% 6	10% HR R_100% 8
AVERAGE VALUES										
CEC	8,45	8,15	7,80	9,30	15,20	14,15	13,05	13,20	9,35	14,75
CEC+ci	7,65	7,50	7,50	9,15	14,15	13,25	12,35	15,15	9,30	14,55
ASTM2D	9,40	8,80	8,30	7,70	18,00	16,10	14,20	13,20	9,50	15,10
ASTM2D+ci	8,40	8,00	7,70	9,10	16,00	14,60	13,30	12,90	9,50	14,60
SCD	8,13	7,83	7,67	9,13	14,87	13,87	12,93	15,27	9,53	14,83
SCD+ci	7,40	7,50	7,50	9,10	13,70	13,20	12,60	15,10	9,30	14,90
RME20	8,40	8,00	7,50	9,30	15,40	14,40	13,20	12,70	9,20	14,70
RME20+ci	7,80	7,60	7,40	9,20	14,30	13,60	12,60	15,00	9,60	14,60
TME20	8,60	8,30	8,00	9,20	16,20	14,50	13,40	13,00	9,40	14,80
TME20+ci	7,90	7,60	7,50	9,00	14,60	13,80	12,90	15,10	9,60	14,50
EtOH15	10,75	10,25	9,20	8,25	22,00	18,60	15,75	13,95	9,90	15,45
EtRE	9,20	9,05	8,20	8,75	17,70	16,00	14,20	13,40	9,85	15,35
STDEVP-%, average	*0,8*	*0,7*	*0,6*	*2,2*	*0,3*	*0,5*	*0,6*	*1,2*	*1,0*	*0,6*

ECE R49, mode	50% HR IM_10% 2	50% HR IM_25% 3	50% HR IM_50% 4	50% HR IM_75% 5	50% HR R_10% 12	50% HR R_25% 11	50% HR R_50% 10	50% HR R_75% 9	50% HR R_100% 6	50% HR R_100% 8
CEC	12,55	14,00	15,90	17,05	17,70	20,95	23,60	24,40	18,50	25,50
CEC+ci	11,70	14,55	15,45	16,85	20,90	20,35	22,85	25,15	18,30	25,50
ASTM2D	10,90	12,90	15,50	16,70	20,80	18,90	25,10	24,10	18,70	25,70
ASTM2D+ci	12,40	12,70	15,10	16,70	18,60	17,40	23,60	23,90	18,70	25,40
SCD	11,83	14,73	15,60	17,10	17,77	20,73	23,30	25,20	18,67	25,77
SCD+ci	11,50	14,80	15,50	17,00	20,30	24,30	23,10	25,40	18,30	25,90
RME20	12,70	12,70	14,90	16,90	17,80	21,10	23,40	23,60	18,20	25,40
RME20+ci	12,20	14,40	15,00	17,10	17,00	20,60	23,10	24,50	18,60	25,30
TME20	10,50	15,10	16,10	17,30	18,80	17,50	24,10	24,30	18,70	25,70
TME20+ci	11,90	14,30	15,90	17,00	17,60	20,70	23,20	24,60	18,80	25,20
EtOH15	12,15	11,90	15,55	17,35	27,50	22,05	22,80	24,75	19,20	26,70
EtRE	10,70	13,15	15,50	17,05	20,65	18,75	24,15	24,35	19,35	26,30
STDEVP-%, average	*2,8*	*2,0*	*0,7*	*0,5*	*0,6*	*0,5*	*2,2*	*0,8*	*0,4*	*0,5*

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COMBUSTION PROPERTIES, VOLVO THD 103 KB, Average results

ECE R49, mode	90% HR IM_10% 2	90% HR IM_25% 3	90% HR IM_50% 4	90% HR IM_75% 5	90% HR R_10% 12	90% HR R_25% 11	90% HR R_50% 10	90% HR R_75% 9	90% HR R_100% 6	90% HR R_100% 8
CEC	31,65	30,20	30,95	32,95	35,40	39,60	41,10	43,45	34,75	45,10
CEC+ci	22,70	30,20	28,20	31,70	46,50	37,65	40,00	42,85	33,55	45,55
ASTM2D	26,50	27,70	31,80	30,00	33,60	41,80	38,90	44,40	35,60	46,50
ASTM2D+ci	25,80	29,60	30,30	32,30	41,70	39,30	41,10	43,10	36,90	43,70
SCD	34,13	30,63	28,40	33,47	45,77	42,27	40,67	43,23	35,30	45,03
SCD+ci	22,50	32,00	27,00	31,90	38,50	38,00	39,90	43,90	34,20	45,90
RME20	29,70	26,30	28,00	32,80	36,70	50,70	41,20	43,00	33,90	45,50
RME20+ci	23,70	31,00	26,60	31,90	40,50	43,50	40,60	42,20	34,40	45,00
TME20	28,50	28,70	31,30	35,50	42,00	39,40	41,50	43,30	34,80	43,90
TME20+ci	23,20	25,90	29,70	31,80	46,20	43,50	39,60	42,20	36,20	42,80
EtOH15	18,00	21,75	26,25	30,65	37,90	33,25	34,90	40,90	32,80	43,35
EtRE	25,00	27,25	28,40	29,75	32,45	35,50	37,55	40,05	35,10	43,00
STDEVP-%, average	*10,8*	*1,1*	*2,2*	*1,1*	*2,2*	*1,9*	*0,6*	*0,5*	*1,2*	*0,8*

ECE R49, mode	max. temp. IM_10% 2	max. temp. IM_25% 3	max. temp. IM_50% 4	max. temp. IM_75% 5	max. temp. R_10% 12	max. temp. R_25% 11	max. temp. R_50% 10	max. temp. R_75% 9	max. temp. R_100% 6	max. temp. R_100% 8
AVERAGE VALUES										
CEC	13,50	19,50	25,00	29,00	19,00	28,00	31,00	36,50	31,00	37,00
CEC+ci	16,00	20,50	24,00	27,00	19,50	32,00	30,00	38,00	31,00	39,00
ASTM2D	11,00	17,00	22,00	27,00	22,00	24,00	32,00	35,00	32,00	37,00
ASTM2D+ci	10,00	16,00	25,00	29,00	20,00	23,00	31,00	34,00	28,00	37,00
SCD	15,33	19,00	22,00	29,00	21,33	27,00	34,33	35,33	31,00	36,67
SCD+ci	16,00	22,00	24,00	25,00	22,00	32,00	30,00	39,00	31,00	37,00
RME20	10,00	16,00	25,00	29,00	19,00	28,00	31,00	33,00	31,00	36,00
RME20+ci	16,00	19,00	24,00	25,00	22,00	32,00	36,00	33,00	31,00	36,00
TME20	17,00	16,00	25,00	26,00	20,00	28,00	37,00	39,00	32,00	37,00
TME20+ci	16,00	19,00	24,00	29,00	23,00	27,00	30,00	33,00	31,00	36,00
EtOH15	13,00	19,30	23,50	25,00	34,50	24,00	32,00	36,50	33,00	41,50
EtRE	11,00	17,00	22,00	26,50	23,00	25,00	33,00	35,00	32,00	38,00
STDEVP-%, average	*9,5*	*5,4*	*4,3*	*1,9*	*5,6*	*0,0*	*3,2*	*3,1*	*0,0*	*3,0*

ECE R49, mode	center of g IM_10% 2	center of g IM_25% 3	center of g IM_50% 4	center of g IM_75% 5	center of g R_10% 12	center of g R_25% 11	center of g R_50% 10	center of g R_75% 9	center of g R_100% 6	center of g R_100% 8
AVERAGE VALUES										
CEC	12,95	13,50	18,50	16,25	18,90	21,00	21,85	25,05	18,65	25,05
CEC+ci	11,00	13,65	13,85	17,45	20,90	20,80	23,10	24,95	17,25	25,20
ASTM2D	12,80	13,50	14,70	19,20	20,90	21,80	26,20	24,00	19,40	25,90
ASTM2D+ci	12,00	13,20	16,70	17,50	20,20	20,50	21,90	35,10	18,60	24,40
SCD	13,03	13,50	14,27	16,33	21,10	23,50	24,63	25,20	18,77	25,57
SCD+ci	11,30	14,30	13,90	17,50	20,00	21,60	21,90	25,30	17,30	25,00
RME20	12,90	13,30	19,40	16,00	19,60	21,50	22,10	25,40	18,10	24,50
RME20+ci	11,90	13,20	13,80	15,70	19,80	21,60	25,20	24,70	17,60	24,60
TME20	12,10	13,90	15,10	17,90	20,50	20,50	25,30	25,50	17,60	25,80
TME20+ci	11,80	12,80	14,30	15,90	20,80	21,40	24,60	24,90	18,90	24,20
EtOH15	12,05	12,40	14,50	16,25	26,50	21,80	22,10	23,65	18,70	26,75
EtRE	11,80	13,70	14,85	19,20	20,45	20,95	28,35	28,35	19,60	26,30
STDEVP-%, average	*4,0*	*1,2*	*3,1*	*1,0*	*0,9*	*3,6*	*4,8*	*0,6*	*1,9*	*1,9*

ECE R49, mode	ign.delay IM_10% 2	ign.delay IM_25% 3	ign.delay IM_50% 4	ign.delay IM_75% 5	ign.delay R_10% 12	ign.delay R_25% 11	ign.delay R_50% 10	ign.delay R_75% 9	ign.delay R_100% 6	ign.delay R_100% 8
CEC	8,75	8,50	7,80	7,30	12,40	10,95	9,60	8,95	8,60	8,80
CEC+ci	7,90	7,70	7,30	7,40	11,50	10,55	8,80	9,05	8,35	8,85
ASTM2D	10,20	9,40	8,30	7,20	14,70	12,90	11,00	9,60	8,00	8,90
ASTM2D+ci	8,70	8,60	7,60	7,20	12,80	11,50	9,90	9,20	8,80	8,40
SCD	8,33	8,00	7,57	7,17	11,93	10,77	9,67	8,93	8,90	8,97
SCD+ci	7,70	7,60	7,20	6,90	10,70	10,10	9,30	8,80	8,00	10,20
RME20	8,70	8,20	7,50	7,30	12,40	11,40	9,90	8,90	8,40	8,90
RME20+ci	8,10	7,70	7,20	7,80	11,80	10,60	9,30	8,70	8,90	9,20
TME20	8,90	8,60	7,90	7,70	13,60	11,40	10,00	9,10	8,30	8,70
TME20+ci	8,00	8,30	7,40	6,70	12,10	11,30	9,70	8,70	9,00	8,70
EtOH15	10,45	10,00	8,65	7,70	17,75	14,50	11,95	9,85	7,50	8,50
EtRE	9,00	8,65	7,90	7,45	14,25	12,25	10,25	9,10	8,45	8,75
STDEVP-%, average	*0,8*	*1,1*	*0,2*	*1,9*	*1,2*	*0,8*	*1,1*	*1,3*	*1,3*	*1,5*

COMBUSTION PROPERTIES, VOLVO THD 103 KB, Average results

ECE R49, mode	5-10 % H IM_10% 2	5-10 % H IM_25% 3	5-10 % H IM_50% 4	5-10 % H IM_75% 5	5-10 % H R_10% 6	5-10 % H R_25% 8	5-10 % H R_50% 9	5-10 % H R_75% 10	5-10 % H R_100% 11	5-10 % H R_100% 12
CEC	0,20	0,40	0,50	2,50	1,75	3,95	1,75	0,95	0,70	0,80
CEC+ci	0,25	0,30	0,70	2,50	1,70	3,70	3,85	1,05	0,70	0,65
ASTM2D	0,20	0,40	0,50	1,00	2,50	4,20	1,10	0,70	0,70	0,80
ASTM2D+ci	0,20	0,40	0,60	2,40	1,70	4,20	1,20	0,90	0,60	0,70
SCD	0,30	0,33	0,60	2,63	1,63	3,70	3,83	0,77	0,60	0,60
SCD+ci	0,20	0,40	0,80	2,70	1,80	2,70	3,80	0,80	0,60	0,50
RME20	0,20	0,30	0,50	2,50	1,80	3,80	1,30	0,80	0,50	0,50
RME20+ci	0,20	0,40	0,70	2,40	1,70	3,40	3,80	0,80	0,50	0,50
TME20	0,20	0,20	0,60	2,50	2,10	4,10	1,40	0,90	0,60	0,60
TME20+ci	0,40	0,30	0,60	2,80	1,60	3,80	3,90	0,70	0,50	0,50
EtOH15	0,30	0,25	0,55	0,80	2,90	3,95	1,10	0,80	1,10	1,25
EtRE	0,20	0,40	0,55	1,80	1,90	4,10	1,30	0,95	0,75	0,70
STDEVP-%, average	*9,4*	*6,8*	*6,4*	*9,9*	*4,4*	*2,6*	*4,9*	*8,0*	*3,2*	*2,3*

ECE R49, mode	10-50 % H IM_10% 2	10-50 % H IM_25% 3	10-50 % H IM_50% 4	10-50 % H IM_75% 5	10-50 % H R_10% 6	10-50 % H R_25% 8	10-50 % H R_50% 9	10-50 % H R_75% 10	10-50 % H R_100% 11	10-50 % H R_100% 12
AVERAGE VALUES										
CEC	4,10	5,85	8,10	7,75	9,15	10,75	11,20	10,55	6,80	2,50
CEC+ci	4,05	7,05	7,95	7,70	9,00	10,95	10,00	10,50	7,10	6,75
ASTM2D	1,50	4,10	7,20	9,00	9,20	10,60	10,90	10,90	2,80	2,80
ASTM2D+ci	4,00	4,70	7,40	7,60	9,20	10,80	11,00	10,30	2,80	2,60
SCD	3,70	6,90	7,93	7,97	9,13	10,93	9,93	10,37	6,87	2,90
SCD+ci	4,10	7,30	8,00	7,90	9,00	11,00	10,30	10,50	11,10	6,60
RME20	4,30	4,70	7,40	7,60	9,00	10,70	10,90	10,20	6,70	2,40
RME20+ci	4,40	6,80	7,60	7,90	9,00	10,70	9,50	10,50	7,00	2,70
TME20	1,90	6,80	8,10	8,10	9,30	10,90	11,30	10,70	3,00	2,60
TME20+ci	4,00	6,70	8,40	8,00	9,20	10,70	9,50	10,30	6,90	3,00
EtOH15	1,40	1,65	6,35	9,10	9,30	11,25	10,80	7,05	3,45	5,50
EtRE	1,50	4,10	7,30	8,30	9,50	10,95	10,95	9,95	2,75	2,95
STDEVP-%, average	*9,9*	*4,4*	*1,4*	*2,1*	*0,8*	*0,7*	*0,8*	*4,9*	*1,0*	*2,1*

ECE R49, mode	50-90 % H IM_10% 2	50-90 % H IM_25% 3	50-90 % H IM_50% 4	50-90 % H IM_75% 5	50-90 % H R_10% 6	50-90 % H R_25% 8	50-90 % H R_50% 9	50-90 % H R_75% 10	50-90 % H R_100% 11	50-90 % H R_100% 12
AVERAGE VALUES										
CEC	19,10	16,20	15,05	15,90	16,25	19,60	19,05	17,50	18,65	17,70
CEC+ci	11,00	15,65	12,75	14,85	15,25	20,05	17,70	17,15	17,30	25,60
ASTM2D	15,60	14,80	16,30	13,30	16,90	20,80	20,30	13,80	22,90	12,80
ASTM2D+ci	13,40	16,90	15,20	15,60	18,20	18,30	19,20	17,50	21,90	23,10
SCD	22,30	15,90	12,80	16,37	16,63	19,27	18,03	17,37	21,53	28,00
SCD+ci	11,00	17,20	11,50	14,90	15,90	20,00	18,50	16,80	13,70	18,20
RME20	17,00	13,60	13,10	15,90	15,70	20,10	19,40	17,80	29,60	18,90
RME20+ci	11,50	16,60	11,60	14,80	15,80	19,70	17,70	17,50	22,90	23,50
TME20	18,00	13,60	15,20	18,20	16,10	18,20	19,00	17,40	21,90	23,20
TME20+ci	11,30	11,60	13,80	14,80	17,40	17,60	17,60	16,40	22,80	28,60
EtOH15	5,85	9,85	10,70	13,30	13,60	16,65	16,15	12,10	11,20	10,40
EtRE	14,30	14,10	12,90	12,70	15,75	16,70	15,70	13,40	16,75	11,80
STDEVP-%, average	*18,1*	*3,2*	*4,1*	*2,5*	*2,1*	*1,3*	*1,3*	*3,8*	*3,6*	*3,9*

ECE R49, mode	duration IM_10% 2	duration IM_25% 3	duration IM_50% 4	duration IM_75% 5	duration R_10% 6	duration R_25% 8	duration R_50% 9	duration R_75% 10	duration R_100% 11	duration R_100% 12
CEC	32,15	30,95	31,45	33,45	35,75	43,10	40,95	38,60	37,10	33,40
CEC+ci	23,20	30,70	28,70	32,45	34,30	43,55	40,60	37,50	35,65	44,50
ASTM2D	27,50	28,70	32,30	30,50	36,60	44,50	41,90	36,40	39,30	31,10
ASTM2D+ci	26,30	30,60	30,80	32,80	37,90	41,70	40,60	38,60	36,80	39,20
SCD	34,63	31,13	28,90	34,13	36,30	42,87	40,73	38,17	39,77	43,43
SCD+ci	23,00	32,50	27,50	32,40	34,70	43,90	41,40	37,40	35,50	36,00
RME20	30,20	26,80	28,50	33,30	34,90	43,50	40,50	38,70	48,20	34,20
RME20+ci	24,20	31,50	27,10	32,90	35,40	43,00	39,70	38,10	41,00	38,50
TME20	29,00	29,20	31,80	36,50	35,80	41,90	40,80	39,00	36,90	40,00
TME20+ci	23,70	26,90	30,20	32,30	37,20	40,80	39,70	37,10	41,50	44,20
EtOH15	18,00	21,75	26,25	30,90	33,30	40,35	37,90	31,90	30,25	34,90
EtRE	25,00	27,25	28,65	30,25	35,60	40,50	37,05	34,55	32,50	29,70
STDEVP-%, average	*10,7*	*1,0*	*2,2*	*1,1*	*1,1*	*0,8*	*0,4*	*0,7*	*2,1*	*2,6*

COMBUSTION PROPERTIES, VOLVO THD 103 KB, Average results

ECE R49, mode	start of inj. IM_10% 2	start of inj. IM_25% 3	start of inj. IM_50% 4	start of inj. IM_75% 5	start of inj. R_10% 12	start of inj. R_25% 11	start of inj. R_50% 10	start of inj. R_75% 9	start of inj. R_100% 6	start of inj. R_100% 8
CEC	-0,50	-0,75	-0,50	-0,50	2,00	2,50	2,50	2,50	-1,00	2,00
CEC+ci	-0,50	-0,50	-0,50	-0,75	2,00	2,00	2,50	2,25	-0,75	2,00
ASTM2D	-1,00	-1,00	-0,50	-0,50	2,50	2,50	2,50	2,50	-1,00	2,00
ASTM2D+ci	-0,50	-1,00	-0,50	-0,50	2,50	2,50	2,50	2,50	-1,00	2,00
SCD	-0,50	-0,50	-0,50	-0,67	2,33	2,50	2,50	2,50	-1,00	2,17
SCD+ci	-0,50	-0,50	-0,50	-0,50	2,50	2,50	2,50	2,50	-0,50	2,00
RME20	-0,50	-0,50	-0,50	-0,50	2,50	2,50	2,50	2,50	-1,00	2,00
RME20+ci	-0,50	-0,50	-0,50	-1,00	2,00	2,50	2,50	2,50	-1,00	2,00
TME20	-0,50	-0,50	-0,50	-1,00	2,00	2,50	2,50	2,50	-1,00	2,00
TME20+ci	-0,50	-1,00	-0,50	-0,50	2,00	2,00	2,50	2,50	-1,00	2,00
EtOH15	0,00	0,00	0,00	-0,25	3,00	3,00	3,00	3,00	-0,50	3,00
EtRE	0,00	0,00	-0,25	-0,50	2,75	3,00	3,00	3,00	-0,50	2,50
STDEVP-%, average				*-33,7*	*3,8*	*0,0*	*0,0*	*2,2*	*-6,7*	*2,2*

ECE R49, mode	75bar IM_10% 2	75bar IM_25% 3	75bar IM_50% 4	75bar IM_75% 5	75bar R_10% 12	75bar R_25% 11	75bar R_50% 10	75bar R_75% 9	75bar R_100% 6	75bar R_100% 8
AVERAGE VALUES										
CEC	5,50	7,50	12,00	15,50	11,75	15,75	21,50	25,00	19,50	28,75
CEC+ci	5,50	7,50	12,00	15,50	11,75	15,50	21,50	25,00	19,50	28,75
ASTM2D	5,50	7,50	12,00	15,50	12,00	16,00	21,50	25,00	19,50	29,00
ASTM2D+ci	5,50	7,50	11,50	15,50	11,50	16,00	21,50	25,00	19,50	29,00
SCD	5,67	7,50	12,00	15,67	11,83	15,83	21,50	25,33	19,83	28,83
SCD+ci	5,50	7,50	12,00	15,50	12,00	16,00	21,50	25,50	19,50	29,00
RME20	5,50	7,50	12,00	16,00	12,00	15,50	21,50	25,00	20,00	29,00
RME20+ci	5,50	7,50	12,00	16,00	11,50	16,00	21,50	25,50	20,00	29,00
TME20	5,50	8,00	12,00	16,00	11,50	16,00	21,50	25,50	20,50	29,50
TME20+ci	6,00	7,50	12,00	16,00	12,00	16,00	21,50	25,50	20,00	29,00
EtOH15	6,50	8,50	13,00	17,50	15,50	17,50	23,00	27,50	21,75	32,75
EtRE	6,25	8,50	12,50	17,00	13,50	17,00	22,50	27,00	21,50	31,75
STDEVP-%, average	*1,6*	*0,0*	*0,0*	*0,3*	*2,0*	*0,6*	*0,0*	*0,2*	*0,5*	*0,8*

ECE R49, mode	peak value IM_10% 2	peak value IM_25% 3	peak value IM_50% 4	peak value IM_75% 5	peak value R_10% 12	peak value R_25% 11	peak value R_50% 10	peak value R_75% 9	peak value R_100% 6	peak value R_100% 8
AVERAGE VALUES										
CEC	65,00	72,00	79,75	90,50	63,25	69,75	82,75	98,50	101,50	115,00
CEC+ci	65,00	71,50	79,25	90,00	64,00	70,00	83,00	98,75	101,50	116,25
ASTM2D	66,50	72,50	81,00	92,50	63,50	70,00	83,00	99,00	102,00	115,00
ASTM2D+ci	66,00	72,00	79,50	91,00	63,50	70,00	83,50	98,50	102,50	115,00
SCD	63,83	70,33	78,50	89,67	63,67	70,00	83,17	99,33	101,00	115,00
SCD+ci	64,00	69,50	78,00	89,00	63,50	70,00	83,00	99,00	101,00	116,50
RME20	65,50	73,50	80,00	91,50	63,50	70,00	82,50	98,00	102,00	114,50
RME20+ci	64,00	70,50	79,00	90,00	63,50	70,00	82,00	98,00	101,50	114,50
TME20	65,00	73,50	79,00	90,50	63,50	70,00	83,50	99,00	100,50	116,00
TME20+ci	62,50	70,50	77,00	89,00	63,50	70,00	83,00	98,50	102,00	114,00
EtOH15	60,75	71,75	80,75	89,00	63,25	68,75	82,25	98,50	96,50	116,25
EtRE	64,00	71,00	78,00	88,75	62,50	69,25	82,50	98,75	98,00	116,25
STDEVP-%, average	*0,7*	*0,6*	*0,3*	*0,2*	*0,2*	*0,3*	*0,3*	*0,2*	*0,2*	*0,4*

ECE R49, mode	angle of pe IM_10% 2	angle of pe IM_25% 3	angle of pe IM_50% 4	angle of pe IM_75% 5	angle of pe R_10% 12	angle of pe R_25% 11	angle of pe R_50% 10	angle of pe R_75% 9	angle of pe R_100% 6	angle of pe R_100% 8
CEC	10,10	9,50	11,60	13,65	-0,60	-0,60	-1,10	-0,60	15,65	-0,30
CEC+ci	9,25	8,75	14,25	14,70	-1,00	-0,95	-0,95	-0,95	16,45	0,20
ASTM2D	11,20	10,50	12,50	14,30	-0,50	-0,60	-0,10	-0,70	16,10	-0,60
ASTM2D+ci	10,10	9,60	14,70	13,70	-1,10	-0,40	0,50	-1,10	15,80	-0,20
SCD	9,70	9,17	12,47	13,47	-0,43	-0,83	-0,70	-0,43	15,40	-0,73
SCD+ci	9,10	8,70	14,10	16,20	-1,30	-1,20	0,30	-0,80	17,90	0,10
RME20	10,10	9,40	11,60	13,70	-0,70	0,10	-1,10	-0,50	15,60	-0,80
RME20+ci	9,30	8,90	14,20	13,30	-0,30	-0,60	-0,80	-0,90	15,50	-0,70
TME20	10,40	9,80	11,80	13,80	-0,50	-1,10	-0,70	-1,10	15,90	-0,30
TME20+ci	9,50	8,90	14,20	13,40	-0,60	-0,40	-0,50	0,00	18,10	0,00
EtOH15	13,00	12,45	10,85	15,30	-1,30	-1,10	-0,55	-0,95	15,55	0,40
EtRE	11,15	10,70	10,90	14,25	-0,95	-0,40	-1,20	-0,70	16,05	-0,15
STDEVP-%, average	*0,5*	*0,7*	*5,8*	*2,1*	*-49,8*	*-36,1*	*-19,9*	*-36,0*	*3,9*	*-15,1*

COMBUSTION PROPERTIES, VOLVO THD 103 KB, Average results

ECE R49, mode	max. rise IM_10% 2	max. rise IM_25% 3	max. rise IM_50% 4	max. rise IM_75% 5	max. rise R_10% 12	max. rise R_25% 11	max. rise R_50% 10	max. rise R_75% 9	max. rise R_100% 6	max. rise R_100% 8
CEC	10,75	13,50	14,25	12,00	3,00	5,50	8,25	6,50	8,25	4,00
CEC+ci	10,50	12,75	11,75	9,75	3,50	5,50	6,00	5,25	6,75	4,00
ASTM2D	13,50	14,50	14,50	14,50	3,00	5,50	8,00	8,00	10,50	4,00
ASTM2D+ci	11,50	13,50	13,50	12,00	3,50	6,00	7,00	6,50	9,50	4,00
SCD	9,50	12,67	12,33	11,17	3,67	6,17	7,67	5,67	7,83	4,00
SCD+ci	9,50	11,50	11,50	10,00	4,00	6,00	7,00	5,00	6,50	4,00
RME20	11,00	15,50	14,50	12,50	3,00	6,00	8,50	7,50	9,00	4,00
RME20+ci	10,00	12,00	12,00	11,50	3,50	5,50	7,50	6,00	7,00	4,00
TME20	11,00	15,50	13,00	12,00	3,00	5,00	8,00	5,50	10,00	4,00
TME20+ci	9,50	13,50	12,00	9,50	4,00	6,00	6,00	4,50	8,00	4,00
EtOH15	10,00	15,00	15,50	15,50	2,50	3,50	7,75	8,50	10,00	5,25
EtRE	11,25	13,50	13,25	12,50	2,50	4,75	7,75	7,00	8,50	4,00
STDEVP-%, average	*2,7*	*3,4*	*2,8*	*2,3*	*1,3*	*6,5*	*6,7*	*6,0*	*2,9*	*1,0*

ECE R49, mode	angle of ris IM_10% 2	angle of ris IM_25% 3	angle of ris IM_50% 4	angle of ris IM_75% 5	angle of ris R_10% 12	angle of ris R_25% 11	angle of ris R_50% 10	angle of ris R_75% 9	angle of ris R_100% 6	angle of ris R_100% 8
AVERAGE VALUES										
CEC	9,40	8,75	11,00	9,90	17,40	15,45	18,95	17,30	8,80	-16,35
CEC+ci	8,55	8,10	10,45	9,45	15,60	14,35	18,10	16,70	8,50	-16,25
ASTM2D	10,50	9,80	8,60	10,50	20,60	18,30	20,00	18,00	9,30	-17,40
ASTM2D+ci	9,30	8,80	7,90	9,90	18,10	16,20	19,00	17,40	8,90	-16,90
SCD	8,90	9,50	10,80	9,67	16,03	16,70	18,50	16,97	8,63	-15,57
SCD+ci	8,40	7,90	10,30	9,40	14,80	19,30	18,00	16,90	8,40	-17,30
RME20	9,40	8,80	11,10	9,80	17,20	15,70	18,60	7,50	8,70	-15,50
RME20+ci	8,70	8,10	10,40	9,50	15,70	14,70	18,20	16,80	8,50	-16,20
TME20	9,60	9,10	11,30	10,00	17,60	21,20	19,20	17,40	9,20	-17,70
TME20+ci	8,80	8,30	7,40	9,50	16,00	14,80	18,50	16,90	8,60	-14,60
EtOH15	12,10	11,70	13,15	11,55	-16,30	21,75	22,60	19,60	10,35	17,35
EtRE	10,30	9,85	8,55	10,50	-16,95	17,90	20,35	18,45	9,40	-16,25
STDEVP-%, average	*0,6*	*3,7*	*0,4*	*0,4*	-2,2	*3,9*	*0,3*	*0,2*	*0,6*	-2,7

ECE R49, mode	IMEP IM_10% 2	IMEP IM_25% 3	IMEP IM_50% 4	IMEP IM_75% 5	IMEP R_10% 12	IMEP R_25% 11	IMEP R_50% 10	IMEP R_75% 9	IMEP R_100% 6	IMEP R_100% 8
AVERAGE VALUES										
CEC	3,17	5,03	8,56	12,39	3,27	5,06	8,00	10,78	16,43	13,80
CEC+ci	3,16	4,99	8,61	12,25	3,25	5,13	8,03	10,91	16,03	13,85
ASTM2D	2,82	5,26	8,57	12,19	3,30	4,98	7,94	10,70	15,74	13,76
ASTM2D+ci	2,96	5,28	9,61	12,15	3,22	5,09	8,00	10,90	15,74	13,80
SCD	3,21	5,08	8,64	12,19	3,26	5,06	7,98	10,93	15,96	13,89
SCD+ci	3,07	5,18	8,62	12,25	3,38	5,03	7,94	10,82	15,96	13,85
RME20	3,07	5,11	8,57	12,60	3,26	5,12	7,96	17,30	15,90	13,90
RME20+ci	3,10	5,23	8,63	12,31	3,19	5,02	7,96	10,83	15,80	13,89
TME20	3,07	5,13	8,63	12,34	3,23	5,02	8,03	10,84	16,00	13,91
TME20+ci	3,29	5,10	8,69	12,27	3,30	5,06	8,01	10,91	16,00	13,83
EtOH15	2,11	4,40	7,81	11,36	2,26	4,18	7,13	9,96	14,91	12,89
EtRE	2,18	4,40	7,84	11,50	2,50	4,31	7,26	9,88	15,21	13,01
STDEVP-%, average	*1,4*	*0,7*	*0,3*	*0,7*	*1,0*	*0,9*	*0,3*	*0,4*	*0,6*	*0,3*

ECE R49, mode	start of combustion IM_10% 2	IM_25% 3	start of combustion IM_50% 4	IM_75% 5	start of combustion R_10% 12	R_25% 11	start of combustion R_50% 10	R_75% 9	start of combustion R_100% 6	R_100% 8
CEC	5,50	5,05	11,35	3,50	9,80	10,85	8,55	14,75	7,15	8,80
CEC+ci	5,05	4,30	4,05	8,10	8,75	9,15	12,75	14,00	2,40	9,85
ASTM2D	6,30	6,20	5,20	12,00	9,80	11,40	16,80	8,60	8,00	13,50
ASTM2D+ci	4,80	4,00	9,20	8,20	9,50	11,40	8,50	12,80	7,20	5,20
SCD	4,83	4,23	4,10	3,60	9,60	12,77	14,90	14,43	7,10	7,97
SCD+ci	4,20	3,90	3,80	8,10	9,50	9,60	8,10	14,20	2,40	5,10
RME20	4,80	5,40	13,00	3,60	9,80	9,60	8,60	15,10	7,10	5,20
RME20+ci	4,20	4,00	4,30	3,60	9,80	9,60	16,20	14,20	2,40	6,30
TME20	6,20	6,10	4,50	8,30	9,80	10,50	15,80	15,10	3,30	12,70
TME20+ci	4,30	4,70	4,30	2,90	9,50	9,60	16,20	14,40	7,10	5,20
EtOH15	7,55	7,20	5,70	4,95	14,90	11,60	11,95	9,20	6,40	14,55
EtRE	5,50	5,85	5,20	12,00	10,90	11,90	21,65	20,35	8,10	13,30
STDEVP-%, average	*3,3*	*6,6*	*6,6*	*4,8*	*4,6*	*10,2*	*15,2*	*1,8*	*8,3*	*29,2*

REGULATED EMISSIONS, VALMET 612 DWI

Mode Load	CO ppm 1 IM25%	CO ppm 2 IM50%	CO ppm 3 R25%	CO ppm 4 R50%
CEC	165,63	48,03	170,33	57,18
CEC+ci	148,98	47,02	145,21	57,07
ASTM2D	219,50	51,01	232,35	57,15
ASTM2D+ci	152,39	46,93	162,31	57,25
SCD	153,12	45,77	140,40	56,22
SCD+ci	118,68	45,53	118,69	48,99
RME	155,26	47,08	149,75	48,03
RME+ci	139,14	37,68	129,65	46,52
TME	185,42	51,12	180,36	55,36
TME+ci	149,93	49,26	148,61	57,02
EtOH15	270,17	57,67	428,72	57,05
EtOH15+ci	200,37	57,13	273,06	56,53
EtRE	57,12	57,12	303,92	57,12
EtRE+ci	170,39	46,90	232,10	54,79

Mode Load	HC ppm 1 IM25%	HC ppm 2 IM50%	HC ppm 3 R25%	HC ppm 4 R50%
CEC	66,38	46,71	59,83	39,42
CEC+ci	63,79	45,06	59,68	38,28
ASTM2D	87,14	56,36	69,63	43,97
ASTM2D+ci	70,05	45,30	63,39	39,67
SCD	55,46	40,93	52,12	33,70
SCD+ci	54,05	41,12	53,29	34,40
RME	58,90	42,31	51,08	35,31
RME+ci	57,59	40,73	48,49	36,16
TME	58,58	36,73	50,48	33,45
TME+ci	62,13	42,04	51,58	36,67
EtOH15	71,64	48,62	91,52	25,02
EtOH15+ci	59,89	44,70	78,95	24,36
EtRE	46,53	46,53	74,91	26,33
EtRE+ci	59,17	45,99	74,01	25,44

Mode Load	NOx ppm 1 IM25%	NOx ppm 2 IM50%	NOx ppm 3 R25%	NOx ppm 4 R50%
CEC	236,33	409,54	147,87	308,02
CEC+ci	239,23	441,20	135,62	294,14
ASTM2D	204,57	307,86	118,80	219,97
ASTM2D+ci	182,55	302,17	109,95	219,22
SCD	168,51	290,09	99,34	206,16
SCD+ci	167,11	312,55	101,65	222,13
RME	174,25	284,94	99,69	205,98
RME+ci	175,55	318,62	104,88	226,20
TME	190,96	305,25	111,55	229,89
TME+ci	188,14	327,17	111,81	240,37
EtOH15	189,20	323,73	98,12	220,67
EtOH15+ci	217,46	363,68	110,08	270,21
EtRE	388,91	388,91	112,13	257,97
EtRE+ci	208,98	369,79	107,12	268,12

COMBUSTION PROPERTIES, VALMET 612 DWI

Mode Load	max. heat r. 1 1200@25%	max. heat r. 2 1200@50%	max. heat r. 3 1200@50%	max. heat r. 4 2100@50%	90% heat r. 1 1200@25%	90% heat r. 2 1200@50%	90% heat r. 3 1200@50%	90% heat r. 4 2100@50%
CEC	6	3	11	10	16,2	17,3	24,6	25,2
CEC+ci	5	3	11	8	18,7	17,5	24,5	30,5
ASTM2D	7	4	13	10	13,6	17	15,9	23,7
ASTM2D+ci	6	4	12	9	13,8	16,9	25,1	30,6
SCD	5,0	3,0	11,0	8,0	18,5	17,2	24,4	28,2
SCD+ci	5	3	10	8	18,6	16,6	24,2	29,1
RME20	5,0	4,0	12,0	8,0	13,6	17,0	25,1	22,5
RME20+ci	5	3	11	8	13,5	16,7	24,4	29
TME20	6	4	12	8	13,4	17,0	25,2	22,1
TME20+ci	5	3	11	8	13,9	17	24,7	22,6
EtOH15	9	5	16	10	16	17,2	18,5	22,7
EtOH15+ci	8	5	15	9	15,1	17,3	28,6	22,8
EtRE	9	5	16	9	16,6	17,3	18,5	22,7
EtRE+ci	8	4	15	9	16,9	17,1	28,2	22,5

Mode Load	5% heat r. 1 1200@25%	5% heat r. 2 1200@50%	5% heat r. 3 1200@50%	5% heat r. 4 2100@50%	max. temp. 1 1200@25%	max. temp. 2 1200@50%	max. temp. 3 1200@50%	max. temp. 4 2100@50%
CEC	3,7	1,8	-7,9	-4,5	14	18	21	23
CEC+ci	3,1	1,7	-8,3	-3,9	14	17	15	23
ASTM2D	4,7	2,5	-7,7	-4,4	8	17	17	24
ASTM2D+ci	4	2,1	-8,6	-5,5	14	18	15	25
SCD	3,3	1,6	-8,6	-5,0	14,0	18,0	15,0	22,0
SCD+ci	3,1	1,4	-9	-4,4	14	17	25	22
RME20	3,5	2,2	-8,4	-4,4	14,0	18,0	15,0	23,0
RME20+ci	3,3	1,3	-7,9	-3,6	14	17	15	23
TME20	4,2	2,2	-9,5	-5,3	14	18	16	22
TME20+ci	3,5	1,6	-8,4	-4,5	14	18	15	22
EtOH15	7	3,3	-4	-4,3	11	18	20	25
EtOH15+ci	5,5	2,8	-8,2	-5,5	15	19	18	24
EtRE	6,7	3,0	-7,8	-3,6	17	18	19	24
EtRE+ci	6,1	2,4	-5,3	-7,6	17	19	18	24

Mode Load	10% heat r. 1 1200@25%	10% heat r. 2 1200@50%	10% heat r. 3 1200@50%	10% heat r. 4 2100@50%	center of gravity of q 1 1200@25%	2 1200@50%	center of gravity of q 3 1200@50%	4 2100@50%
CEC	4,1	2,4	4,3	6,6	6,9	7,0	14,0	13,7
CEC+ci	3,5	2,3	0,7	7,1	6,7	7,0	13,6	14,6
ASTM2D	5,1	3,1	2,7	8,3	6,8	6,5	12,7	14,3
ASTM2D+ci	4,3	2,6	1,5	7,4	6,8	6,7	14,2	14,4
SCD	3,7	2,2	0,8	6,5	6,4	6,8	13,5	13,7
SCD+ci	3,6	2,1	2,5	6,7	6,7	6,8	13,9	14,4
RME20	4,1	2,7	0,3	6,7	6,6	6,6	14,2	13,1
RME20+ci	3,8	2	9	6,5	6,4	6,4	13,5	13,7
TME20	4,6	2,6	-1,5	6,6	6,8	6,9	14,0	13,1
TME20+ci	4	2,3	9,1	6,3	6,5	6,8	13,7	13,1
EtOH15	7,4	3,8	13,9	8,1	9,5	7,1	15,7	13,5
EtOH15+ci	6	3,3	2	7,4	8,4	7,2	16,3	13,6
EtRE	7,2	3,4	13,1	7,4	9,4	7,1	15,2	13,3
EtRE+ci	6,5	3,0	12,2	6,8	9,2	6,9	16,5	13,2

Mode Load	50% heat r. 1 1200@25%	50% heat r. 2 1200@50%	50% heat r. 3 1200@50%	50% heat r. 4 2100@50%	Ignition Delay 1 1200@25%	Ignition Delay 2 1200@50%	Ignition Delay 3 1200@50%	Ignition Delay 4 2100@50%
CEC	6,1	7,6	12,0	14,1	6,0	5,0	7,2	6,4
CEC+ci	5,7	8,1	11,8	15,8	5,2	4,6	7,1	6,1
ASTM2D	6,8	5,7	13,3	12,4	6,6	5,7	9,2	7,9
ASTM2D+ci	6,2	6,9	12,2	14,3	6,1	5,3	8,3	6,3
SCD	5,6	7,7	11,7	14,6	5,4	5,0	7,7	6,1
SCD+ci	5,7	7,8	11,6	15,4	5,4	5	6,9	5,6
RME20	5,8	6,6	12,3	12,5	6,0	5,4	7,8	7,1
RME20+ci	5,7	7,3	11,9	14,4	5,4	5,1	7,2	6,6
TME20	6,3	6,1	12,5	12,1	6,1	5,8	8,0	7,1
TME20+ci	5,7	7,3	11,9	13,5	5,4	5,0	7,6	6,4
EtOH15	9,1	5,9	16,4	11,9	7,5	6,2	10,0	8,3
EtOH15+ci	7,8	6,3	15,3	12,4	6,1	5,2	7,7	6,8
EtRE	9,0	6,0	15,8	12,0	6,3	6,2	9,1	7,3
EtRE+ci	8,6	6,0	14,9	12,2	5,1	5,0	8,2	7,2

COMBUSTION PROPERTIES, VALMET 612 DWI

Mode Load	start of inject 1 1200@25%	start of inject 2 1200@50%	start of inject 3 1200@25%	start of inject 4 2100@50%	max. rise 1 1200@25%	max. rise 2 1200@50%	max. rise 3 1200@50%	max. rise 4 2100@50%
CEC	-4,0	-5,0	0,5	-1,8	14,1	13,8	8,6	6,6
CEC+ci	-4,0	-5,0	0,5	-1,0	12,0	12,5	8,0	5,5
ASTM2D	-4	-5	0	-1,5	17	17	10,5	8,5
ASTM2D+ci	-4	-5	0	-1	15,5	15	9	7
SCD	-4,0	-5,0	0,0	-1,5	13,5	14,5	10,0	5,5
SCD+ci	-4	-5	0	-1	12,5	12,5	7	5
RME20	-4,0	-5,0	0,5	-2,5	15,0	15,0	9,0	7,0
RME20+ci	-4	-5,5	0,5	-2	12,5	12,5	8	6
TME20	-4,0	-5,5	0,5	-2,5	15,0	16,0	9,5	8,0
TME20+ci	-4	-5	0,5	-2	14	14,5	8,5	7
EtOH15	-2,5	-5	2	-2	15,5	21,5	8,5	10
EtOH15+ci	-2,5	-4,5	2,5	-1,5	15	17,5	7,5	8
EtRE	-2,0	-5,0	2,0	-2,0	13,5	18,0	7,0	9,0
EtRE+ci	-1,5	-5,0	2,0	-2,0	11,5	16,0	6,5	7,0

Mode Load	noin 75bar 1 1200@25%	noin 75bar 2 1200@50%	noin 75bar 3 1200@50%	noin 75bar 4 2100@50%	angle of rise 1 1200@25%	angle of rise 2 1200@50%	angle of rise 3 1200@50%	angle of rise 4 2100@50%
CEC	6,625	9,375	10,5	15,375	5,5	3,1	10,5	7,5
CEC+ci	6,5	9,0	10,5	15,0	4,5	3,0	10,5	8,0
ASTM2D	6	9,5	11	15,5	7	4	12,5	9,5
ASTM2D+ci	6,5	9,5	11	15	6	3,5	11	8,5
SCD	6,0	9,0	11,0	15,0	5,0	3,0	10,5	7,5
SCD+ci	6,5	9,5	11	15	5	2,5	10	7,5
RME20	6,5	9,5	10,5	15,5	5,5	3,5	11,0	8,0
RME20+ci	6,5	9,5	10,5	15,5	5	2,5	10,5	7,5
TME20	6,5	9,5	11,0	15,0	6,0	3,5	11,5	8,0
TME20+ci	6,5	9,5	11	15	5,5	3	10,5	7,5
EtOH15	7,5	10	11,5	15,5	9	5	16,5	9,5
EtOH15+ci	7,5	10	11,5	15,5	7,5	4,5	14,5	9
EtRE	8,0	10,0	12,0	15,5	9,0	4,5	14,5	8,5
EtRE+ci	7,5	10,0	12,0	15,5	8,0	4,0	13,5	8,0

Mode Load	peak value 1 1200@25%	peak value 2 1200@50%	peak value 3 1200@50%	peak value 4 2100@50%	IMEP 1 1200@25%	IMEP 2 1200@50%	IMEP 3 1200@50%	IMEP 4 2100@50%
CEC	80,1	93,3	77,5	86,4	5,6	9,2	5,6	9,7
CEC+ci	79,0	93,5	77,0	84,0	5,2	9,0	5,4	9,1
ASTM2D	83	97,5	78,5	89,5	5,2	9,1	5,7	9,2
ASTM2D+ci	82,5	94	80	87,5	5,41	9,28	5,82	9,23
SCD	80,0	93,0	80,0	84,5	5,3	9,1	5,9	9,4
SCD+ci	78	93	76	83	5,32	9,25	5,5	9,2
RME20	81,0	94,0	78,5	88,5	5,1	9,0	5,6	9,4
RME20+ci	78	93	76	85	5,24	9,04	5,33	9,13
TME20	82,0	95,5	79,0	90,5	5,4	9,1	5,8	9,5
TME20+ci	80,5	94	78,5	86,5	5,1	9,1	5,8	9,4
EtOH15	81,5	102	75,5	92	5,8	9,3	6,03	9,31
EtOH15+ci	81	98	72,5	89,5	6,1	9,5	6,0	9,2
EtRE	79,0	100,0	74,0	90,0	5,5	9,3	6,0	9,3
EtRE+ci	75,0	95,5	73,5	88,5	5,5	9,3	6,0	9,5

Mode Load	angle of peak 1 1200@25%	2 1200@50%	angle of peak 3 1200@50%	4 2100@50%	start of combustion 1 1200@25%	2 1200@50%	start of combustion 3 1200@50%	4 2100@50%
CEC	7,5	10,8	14,1	12,5	2,0	0,0	7,7	4,6
CEC+ci	7,0	11,0	14,0	12,0	1,2	-0,4	7,6	5,1
ASTM2D	8	6	15	13	2,6	0,7	9,2	6,4
ASTM2D+ci	7,5	11,5	15	12,5	2,1	0,3	8,3	5,3
SCD	7,5	11,0	14,5	11,5	1,4	0,0	7,7	4,6
SCD+ci	7	11	13,5	12	1,4	0	6,9	4,6
RME20	7,5	11,5	15,0	11,5	2,0	0,4	8,3	4,6
RME20+ci	7,5	11	14,5	11,5	1,4	-0,4	7,7	4,6
TME20	7,5	5,5	15,5	11,5	2,1	0,3	8,5	4,6
TME20+ci	7,5	11	15	11	1,4	0	8,1	4,4
EtOH15	10,5	7	19,5	13	5	1,2	12	6,3
EtOH15+ci	8,5	6,5	18	12,5	3,6	0,7	10,2	5,3
EtRE	10,0	6,5	19,0	12,0	4,3	1,2	11,1	5,3
EtRE+ci	10,0	6,0	18,0	12,0	3,6	0,0	10,2	5,2

IEA FUEL CHARACTERIZATION

Audi A4 TDI tests with different fuels

Fuel code	Test n:o	Expla-nation	CO [g/km] 1	2	3	4	5	HC [g/km] 1	2	3	4	5	NOx [g/km] 1	2	3	4	5
F1	*96108*	*CEC*	*0,055*	*0,055*	*0,057*	*0,033*	*0,030*	*0,015*	*0,018*	*0,019*	*0,016*	*0,018*	*2,070*	*1,380*	*3,560*	*0,845*	*0,468*
F1	*96121*	*CEC*	*0,095*	*0,093*	*0,089*	*0,071*	*0,069*	*0,019*	*0,019*	*0,027*	*0,021*	*0,023*	*2,120*	*1,389*	*3,470*	*0,907*	*0,472*
F1	*96146*	*CEC*	*0,079*	*0,070*	*0,081*	*0,056*	*0,054*	*0,022*	*0,018*	*0,028*	*0,018*	*0,020*	*2,120*	*1,384*	*3,720*	*0,948*	*0,479*
	Stdevp, abs	*CEC*	*0,016*	*0,016*	*0,014*	*0,016*	*0,016*	*0,003*	*0,000*	*0,004*	*0,002*	*0,002*	*0,024*	*0,004*	*0,103*	*0,042*	*0,005*
	Stdevp, %	*CEC*	*21,5*	*21,5*	*18,0*	*29,3*	*31,5*	*15,4*	*2,6*	*16,3*	*11,2*	*10,1*	*1,1*	*0,3*	*2,9*	*4,7*	*1,0*
	Stdevp, %	*average*	*24,4*					*11,1*					*2,0*				
	Average	CEC	0,076	0,073	0,076	0,053	0,051	0,019	0,018	0,025	0,018	0,020	2,103	1,384	3,583	0,900	0,473
F7	96114	CEC+ci	0,083	0,086	0,080	0,062	0,062	0,017	0,018	0,021	0,018	0,020	2,010	1,323	3,420	0,830	0,461
F2	96110	ASTM2d	0,062	0,059	0,061	0,042	0,038	0,022	0,025	0,026	0,021	0,022	2,140	1,380	3,480	0,842	0,480
F8	96115	ASTM2D+ci	0,076	0,074	0,079	0,052	0,047	0,021	0,023	0,025	0,021	0,024	2,080	1,394	3,450	0,863	0,492
F3	96111	SCD	0,058	0,051	0,057	0,040	0,032	0,015	0,018	0,026	0,018	0,020	2,100	1,370	3,510	0,844	0,458
F9	96116	SCD+ci	0,076	0,070	0,082	0,056	0,042	0,017	0,020	0,026	0,018	0,020	2,140	1,488	3,610	0,996	0,519
SLREF60	96119	CNref60	0,094	0,072	0,081	0,058	0,042	0,048	0,040	0,041	0,047	0,041	2,050	1,401	3,230	1,052	0,559
SLREF43	96120	CNref43	0,104	0,105	0,093	0,075	0,090	0,025	0,023	0,027	0,024	0,027	2,260	1,483	3,610	0,954	0,505
F4	96112	RME20	0,060	0,061	0,065	0,044	0,042	0,015	0,018	0,020	0,017	0,021	2,110	1,340	3,500	0,843	0,468
F10	96117	RME20+ci	0,080	0,073	0,080	0,061	0,059	0,015	0,017	0,022	0,016	0,017	2,300	1,510	3,650	1,018	0,513
F5	96113	TME20	0,075	0,089	0,065	0,044	0,042	0,013	0,018	0,020	0,017	0,021	2,130	1,412	3,760	0,894	0,502
F11	96118	TME20+ci	0,087	0,098	0,091	0,081	0,092	0,017	0,019	0,023	0,018	0,023	2,260	1,434	3,640	1,004	0,497
F6	96147	EtOH15	0,101	0,082	0,086	0,076	0,056	0,064	0,072	0,057	0,066	0,071	2,030	1,416	3,370	1,054	0,547
F12	96148	EtOH15+ci	0,096	0,071	0,087	0,066	0,052	0,064	0,063	0,060	0,067	0,070	2,050	1,434	3,400	1,010	0,530
F18	96149	EtRE	0,094	0,075	0,083	0,063	0,043	0,062	0,068	0,061	0,063	0,062	1,960	1,378	3,450	0,979	0,495
F19	96150	EtRE+ci	0,094	0,078	0,087	0,060	0,043	0,062	0,063	0,054	0,054	0,056	2,030	1,387	3,570	0,955	0,502
	Max. fuel effect, %		*55,9*	*71,0*	*46,0*	*70,3*	*115,2*	*164,6*	*168,2*	*122,9*	*162,1*	*161,4*	*16,1*	*13,3*	*15,1*	*23,8*	*20,2*

Loads used:

1	4000 rpm, 50 %
2	4000 rpm, 25 %
3	2600 rpm, 100 %
4	2600 rpm, 50 %
5	2600 rpm, 25 %

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MODE IMUS_P mbar | start of inject. | 100bar DU_1 | peak vlue | angle of peak | max. rise RX_3 | angle of rise | IMEP PI | start of comb. | max. heat release | 5% HR | 10% HR | 50% HR | 90% HR | max. | center | ignition APPENDIX

	MODE	IMUS_P mbar	start of inject.	100bar DU_1	peak vlue	angle of peak	max. rise RX_3	angle of rise	IMEP PI	start of comb.	max. heat release	5% HR Ala	10% HR Alb	50% HR Alc	90% HR Ald	max. temp.	center of grav.	ignition delay	5-10 % HR	10-50 % HR	50-90 % HF	duration of comb.
96108D	1	6930	-8,5	12,5	96,5	8,0	3,5	-10,0	10,1	-17,6	11	-4,4	0,5	14,4	30,7	31,0	12,1	4,1	4,9	13,9	16,3	39,2
19.08-96	2	6730	-7,0	13,0	89,5	6,5	3,5	-9,0	8,0	-9,9	10	-4,7	-0,3	14,3	29,4	27,0	12,4	2,3	4,4	14,6	15,1	36,4
CEC	3	8400	-6,5	16,0	107,5	9,5	3,5	-13,0	14,1	-10,7	15	1,9	4,6	15,8	29,2	27,0	14,1	8,4	2,7	11,2	13,4	35,7
	4	6850	-0,5	15	85,5	0,5	3,0	-16,5	9,1	5,1	21,0	7,2	9,8	20,2	35,4	32,0	19,1	7,7	2,6	10,4	15,2	35,9
	5	4390	1	14,5	74,0	0,5	3,0	-11,5	6,5	9,1	14,0	9,8	11,9	20,7	36,2	28,0	20,0	8,8	2,1	8,8	15,5	35,2
96109D	1	7030	-8,5	12,5	102,0	9,5	3,5	-11,5	10,6	-14,8	9,0	-5,8	-0,5	13,9	29,9	30,0	12,0	2,7	5,3	14,4	16,0	38,4
19.08-96	2	6720	-7,0	13,0	90,5	8,5	3,0	-15,0	8,4	-12,9	10,0	-4,5	-0,3	14,2	29,4	28,0	12,2	2,5	4,2	14,5	15,2	36,4
F1/CEC	3	8610	-6,0	15,5	110,5	9,0	3,5	-16,0	14,4	-8,8	17,0	2,4	4,9	16,0	29,5	28,0	14,2	8,4	2,5	11,1	13,5	35,5
	4	6730	-0,5	15	85,5	0,0	3,0	-15,0	9,2	3,7	23,0	8,3	10,2	20,4	34,3	34,0	19,0	8,8	1,9	10,2	13,9	34,8
	5	4380	1	14,5	73,5	0,0	3,0	-12,0	6,7	6,4	14,0	9,2	11,8	20,4	35,1	34,0	19,5	8,2	2,6	8,6	14,7	34,1
96121D	1	7080	-8,5	13,0	102,5	9,0	3,5	-12,0	10,1	-12,6	9,0	-5,0	0,1	12,7	28,1	27,0	11,3	3,5	5,1	12,6	15,4	36,6
23.08.-96	2	6720	-7,0	13,5	92,5	8,0	3,5	-10,5	8,0	-11,8	11,0	-4,2	-0,3	12,9	27,3	27,0	11,1	2,8	3,9	13,2	14,4	34,3
F1/CEC	3	8660	-6,5	17,0	113,0	9,0	3,5	-15,5	13,8	-5,9	16,0	1,4	4,1	15,4	28,8	27,0	13,7	7,9	2,7	11,3	13,4	35,3
	4	6710	-0,5	15,5	87,5	0,5	3,0	-15,5	8,7	3,6	21,0	8,0	9,8	19,5	33,6	29,0	18,4	8,5	1,8	9,7	14,1	34,1
	5	4280	1	15,0	74,5	1,0	3,0	-11,5	6,2	8,3	14,0	8,0	11,5	18,0	33,6	28,0	18,9	7,0	3,5	6,5	15,6	32,6
96146D	1	7120	-8,5	12,5	98,0	8,5	3,5	-8,0	7,4	-14,5	9,0	-2,4	1,0	12,6	26,9	26,0	10,6	6,1	3,4	11,6	14,3	35,4
09.09.96	2	6810	-7,0	13,5	89,5	5,0	3,5	-12,0	5,3	-12,9	11,0	-3,0	0,5	12,7	26,3	25,0	10,6	4,0	3,5	12,2	13,6	33,3
F1/CEC	3	8630	-7,0	16,0	111,5	8,5	3,5	-14,5	9,9	-9,6	16,0	2,5	4,5	14,6	25,4	26,0	12,6	9,5	2,0	10,1	10,8	32,4
	4	6730	-0,5	15	86,0	0,0	3,0	-17,0	5,5	5,2	14,0	9,4	10,5	18,5	29,3	28,0	16,9	9,9	1,1	8,0	10,8	29,8
	5	4170	1	14,5	72,0	-0,5	2,5	-15,0	3,5	6,7	15,0	10,0	11,5	16,5	27,5	29,0	17,0	9,0	1,5	5,0	11,0	26,5
96114D	1	7050	-8,5	13,0	97,5	9,0	3,5	-8,5	10,5	-17,4	9,0	-5,4	-0,3	14,6	30,8	32,0	12,4	3,1	5,1	14,9	16,2	39,3
21.08.-96	2	6750	-7,5	13,0	90,0	4,0	3,5	-8,0	8,4	-11,9	9,0	-5,2	-0,3	14,4	29,4	29,0	12,3	2,3	4,9	14,7	15,0	36,9
F7/CEC+ci	3	8500	-6,5	16,5	108,0	9,0	3,5	-14,5	14,3	-10,7	14,0	2,8	5,3	16,2	29,1	28,0	14,4	9,3	2,5	10,9	12,9	35,6
	4	6430	-0,5	15,0	85,0	0,0	3,0	-15,0	9,1	5,3	20,0	6,3	9,7	20,5	37,0	32,0	19,6	6,8	3,4	10,8	16,5	37,5
	5	4050	1,5	14,5	73,0	-0,5	3,0	-11,0	6,6	4,4	14,0	6,0	11,5	20,0	35,7	27,0	19,5	4,5	5,5	8,5	15,7	34,2
96110D	1	6820	-8,5	12,5	96,5	9,0	3,5	-9,0	10,1	-12,9	9,0	-4,2	0,5	14,4	30,2	29,0	12,4	4,3	4,7	13,9	15,8	38,7
20.08-96	2	6720	-7,0	13,0	89,0	7,0	3,5	-7,5	8,1	-17,6	9,0	-4,8	-0,6	14,1	29,4	28,0	11,6	2,2	4,2	14,7	15,3	36,4
F2/ASTM2D	3	8550	-6,5	16,0	110,5	9,0	3,5	-15,0	14,1	-5,9	14,0	3,1	5,3	16,0	28,7	28,0	14,3	9,6	2,2	10,7	12,7	35,2
	4	6620	-0,5	15	85,0	-0,5	3,5	-9,0	9,0	5,2	21,0	8,6	10,3	20,3	34,3	34,0	19,1	9,1	1,7	10,0	14,0	34,8
	5	4320	1	14,5	73,5	0,0	3,0	-13,5	6,8	4,4	14,0	6,0	11,8	17,8	32,7	31,0	18,7	5,0	5,8	6,0	14,9	31,7
96115D	1	6940	-9,0	12,5	96,0	8,0	3,5	-10,5	10,4	-11,8	11,0	-3,6	0,9	15,1	31,5	30,0	12,9	5,4	4,5	14,2	16,4	40,5
22.08.-96	2	6750	-7,5	13,0	90,5	9,0	3,5	-7,0	8,4	-12,9	9,0	-5,0	-0,4	14,3	29,5	28,0	12,1	2,5	4,6	14,7	15,2	37,0
F8/ASTM2D+ci	3	8500	-6,5	16,5	110,5	9,5	3,5	-15,0	14,7	-12,5	15,0	1,6	4,6	15,9	28,9	28,0	13,9	8,1	3,0	11,3	13,0	35,4
	4	6363	0	15,5	85,0	-0,5	3,0	-16,5	9,2	6,4	22,0	4,5	9,9	20,6	35,4	35,0	19,6	4,5	5,4	10,7	14,8	35,4
	5	4320	1,5	14,5	73,5	0,5	3,0	-13,0	6,9	6,1	15,0	7,0	11,5	18,9	35,6	30,0	19,4	5,5	4,5	7,4	16,7	34,1
96111D	1	7020	-8,5	12,5	100,5	9,5	3,5	-10,0	10,6	-13,9	9,0	-3,9	0,7	14,2	30,6	32,0	12,2	4,6	4,6	13,5	16,4	39,1
20.08.-96	2	6730	-7,0	12,5	90,5	7,0	3,0	-14,0	8,2	-17,6	11,0	-7,6	-2,2	14,0	29,9	27,0	11,6	-0,6	5,4	16,2	15,9	36,9
F3/SCD	3	8510	-6,5	16,0	109,0	10,0	3,5	-14,0	14,1	-8,9	15,0	2,0	4,7	15,7	28,4	28,0	14,0	8,5	2,7	11,0	12,7	34,9
	4	6540	-0,5	15	84,5	0,5	3,0	-15,0	8,9	5,3	23,0	7,8	9,8	20,0	33,2	33,0	18,9	8,3	2,0	10,2	13,2	33,7
	5	4140	1,5	14	72,0	-0,5	2,5	-16,5	6,3	4,5	14,0	9,0	11,6	19,6	34,4	27,0	19,0	7,5	2,6	8,0	14,8	32,9
96116D	1	6920	-8,5	12,5	96,0	8,5	3,5	-8,5	10,5	-13,9	9,0	-5,7	-0,5	14,7	31,1	34,0	12,9	2,8	5,2	15,2	16,4	39,6
22.08.-96	2	6530	-7,0	13,0	88,5	5,5	3,0	-15,0	8,3	-16,4	11,0	-4,1	-0,1	14,7	30,1	29,0	12,2	2,9	4,0	14,8	15,4	37,1
F9/SCD+ci	3	8450	-7,0	17,0	111,5	9,0	3,5	-14,0	14,2	-10,7	17,0	2,0	4,4	15,6	28,6	28,0	13,5	9,0	2,4	11,2	13,0	35,6
	4	6630	0	15,5	87,0	1,0	3,0	-15,0	8,6	3,6	14,0	2,0	8,8	18,6	31,1	29,0	17,8	2,0	6,8	9,8	12,5	31,1
	5	4430	1	14,5	74,0	-0,5	2,5	-18,5	6,7	6,1	14,0	7,8	10,6	18,4	32,1	27,0	18,3	6,8	2,8	7,8	13,7	31,1
96112D	1	6900	-8,5	12,5	97,5	9,0	3,5	-8,0	10,1	-13,9	9,0	-4,0	0,6	14,2	30,4	31,0	12,3	4,5	4,6	13,6	16,2	38,9
20.08.-96	2	6700	-7,5	12,5	90,5	6,5	3,5	-9,0	8,2	-17,6	11,0	-4,6	-0,2	13,8	29,0	28,0	11,5	2,9	4,4	14,0	15,2	36,5
F4/RME20	3	8520	-6,5	16,0	109,0	10,0	3,5	-14,0	14,2	-8,9	14,0	2,7	5,1	15,9	29,1	27,0	14,2	9,2	2,4	10,8	13,2	35,6
	4	6660	-0,5	15	85,5	0,5	3,5	-12,0	9,1	3,7	21,0	8,2	9,8	20,0	33,8	32,0	18,6	8,7	1,6	10,2	13,8	34,3
	5	4 270	1,5	14,5	73,0	-0,5	2,5	-15,5	6,6	6,5	14,0	8,0	11,6	19,4	34,4	30,0	19,2	6,5	3,6	7,8	15,0	32,9
96117D	1	7210	-8,5	13,5	103,0	9,5	3,5	-12,0	10,3	-12,7	9,0	-3,9	0,4	13,0	28,2	28,0	11,4	4,6	4,3	12,6	15,2	36,7
22.08.-96	2	6740	-7,5	13,5	92,0	8,0	3,5	-10,0	7,9	-11,9	11,0	-5,4	-0,9	12,8	27,3	26,0	11,1	2,1	4,5	13,7	14,5	34,8
F10/RME20+ci	3	8540	-6,5	17,0	112,5	9,5	3,5	-14,0	14,0	-13,6	17,0	0,9	3,8	15,4	28,0	28,0	13,5	7,4	2,9	11,6	12,6	34,5
	4	6930	-0,5	16,0	87,5	-0,5	3,0	-16,5	8,9	5,0	14,0	7,5	9,4	19,0	31,8	28,0	17,9	8,0	1,9	9,6	12,8	32,3
	5	4320	1,5	14,5	74,0	0,5	3,0	-10,0	6,5	6,1	14,0	-2,0	10,0	17,6	31,4	28,0	18,2	-3,5	12,0	7,6	13,8	29,9

AUDI 1.9 TDI, CYLINDER PRESSURE ANALYSIS

	MODE	IMUS_P mbar	start of inject.	100bar DU_1	peak vlue	angle of peak	max. rise RX_3	angle of rise	IMEP PI	start of comb.	max. heat release	5% HR Ala	10% HR Alb	50% HR Alc	90% HR Ald	max. temp.	center of grav.	ignition delay	5-10 % HR	10-50 % HF	50-90 % HF	duration of comb.
96113D	1	6970	-8,5	12,5	100,0	9,5	3,5	-10,5	10,3	-12,7	10,0	-5,9	-0,7	13,8	29,9	29,0	12,0	2,6	5,2	14,5	16,1	38,4
21.08.-96	2	6730	-7,5	12,5	91,0	8,5	3,5	-10,5	8,3	-11,9	10,0	-4,6	-0,6	13,9	29,1	28,0	12,0	2,9	4,0	14,5	15,2	36,6
F5/TME20	3	8730	-6,5	16,0	110,5	9,5	3,5	-14,5	14,4	-8,8	14,0	2,3	5,0	16,1	28,9	28,0	14,3	8,8	2,7	11,1	12,8	35,4
	4	6660	-0,5	15,5	86,0	0,5	3,0	-15,5	9,2	3,7	22,0	8,2	10,2	20,7	35,0	34,0	19,4	8,7	2,0	10,5	14,3	35,5
	5	4100	1,5	14,5	73,5	1,0	2,5	-16,0	6,6	4,4	15,0	6,3	11,6	19,9	36,0	32,0	19,8	4,8	5,3	8,3	16,1	34,5
96118D	1	7120	-9,0	14,0	103,0	9,0	3,5	-12,0	10,7	-13,8	9,0	-4,0	0,4	13,0	28,4	28,0	11,3	5,0	4,4	12,6	15,4	37,4
23.08.-96	2	6740	-7,0	13,5	91,5	5,5	3,0	-14,0	8,0	-17,6	11,0	-4,3	-0,2	13,2	27,9	25,0	10,8	2,7	4,1	13,4	14,7	34,9
F11/TME20+ci	3	8510	-6,5	17,0	113,5	9,5	3,5	-16,0	13,9	-11,5	16,0	1,5	4,1	15,3	28,0	27,0	13,4	8,0	2,6	11,2	12,7	34,5
	4	6620	-0,5	16,0	87,0	-0,5	3,5	-11,0	9,0	5,1	12,0	0,8	8,9	18,8	31,4	32,0	17,8	1,3	8,1	9,9	12,6	31,9
	5	4150	1,0	14,5	73,5	0,5	3,0	-11,0	6,6	4,4	14,0	5,0	10,8	17,5	31,0	28,0	18,1	4,0	5,8	6,7	13,5	30,0
96147D	1	7260	-9,0	13,0	101,5	7,5	3,5	-9,5	7,3	-13,7	8,0	-4,4	-0,1	11,4	25,6	24,0	9,7	4,6	4,3	11,5	14,2	34,6
09.09.96	2	6820	-7,5	13,0	92,5	7,0	3,0	-12,5	5,4	-13,9	10,0	-3,3	0,3	11,9	25,4	25,0	9,9	4,2	3,6	11,6	13,5	32,9
F6/EtOH15	3	8400	-7,0	17,0	108,0	8,0	3,5	-16,0	9,3	-8,8	15,0	2,7	4,3	14,3	25,6	26,0	12,3	9,7	1,6	10,0	11,3	32,6
	4	6770	-1	15	86,5	0,0	3,0	-15,5	5,6	5,2	20,0	9,1	10,0	18,2	28,7	27,0	16,3	10,1	0,9	8,2	10,5	29,7
	5	4320	0,5	14,5	73,5	-0,5	2,5	-17,0	3,5	6,5	14,0	10,6	11,6	15,3	26,7	25,0	15,8	10,1	1,0	3,7	11,4	26,2
96148D	1	7480	-9,0	13,5	104,0	8,5	3,5	-11,5	7,7	-14,8	9,0	-3,1	0,5	11,3	25,6	24,0	9,6	5,9	3,6	10,8	14,3	34,6
09.09.96	2	6880	-8,0	13,0	94,5	7,0	3,0	-13,5	5,6	-12,8	11,0	-5,0	-0,8	11,3	24,8	25,0	9,5	3,0	4,2	12,1	13,5	32,8
F12/EtOH15+ci	3	8660	-7,0	17,0	112,0	8,5	3,5	-14,0	9,8	-8,8	15,0	2,6	4,3	14,4	25,7	26,0	12,2	9,6	1,7	10,1	11,3	32,7
	4	6620	-1	15	87,0	0,5	3,0	-16,0	5,6	5,1	11,0	8,8	10,0	17,9	28,5	26,0	16,4	9,8	1,2	7,9	10,6	29,5
	5	4250	0	14,0	73,5	-0,5	2,5	-16,5	3,7	7,6	12,0	10,0	10,9	15,2	26,7	27,0	15,7	10,0	0,9	4,3	11,5	26,7
96149D	1	7330	-8,5	13,0	102,5	9,0	3,5	-9,5	7,5	-14,8	8,0	-2,9	0,9	11,9	25,7	26,0	9,9	5,6	3,8	11,0	13,8	34,2
09.09.96	2	6900	-7,5	12,5	94,0	7,5	3,0	-12,5	5,6	-13,9	8,0	-2,8	1,0	11,8	24,9	24,0	9,5	4,7	3,8	10,8	13,1	32,4
F18/EtRE	3	8620	-7,0	16,5	112,5	9,5	3,5	-13,5	9,7	-8,8	15,0	2,4	4,0	14,3	25,6	27,0	12,3	9,4	1,6	10,3	11,3	32,6
	4	6520	-1	15	85,0	-0,5	3,0	-17,0	5,7	5,3	12,0	8,3	9,5	17,6	27,6	26,0	16,1	9,3	1,2	8,1	10,0	28,6
	5	4230	0,5	14,5	72,0	-0,5	3,0	-11,0	3,8	6,7	13,0	10,7	11,6	15,6	27,2	27,0	16,3	10,2	0,9	4,0	11,6	26,7
96150D	1	7350	-8,5	13,0	101,5	8,5	3,5	-9,5	7,5	-14,8	9,0	-2,8	0,7	11,9	25,5	27,0	10,0	5,7	3,5	11,2	13,6	34,0
09.09.96	2	6890	-7,5	12,0	93,5	8,0	3,5	-9,5	5,6	-12,8	9,0	-2,7	0,8	11,8	25,1	23,0	9,8	4,8	3,5	11,0	13,3	32,6
F19/EtRE+ci	3	8440	-7,5	16,5	111,5	8,0	3,5	-14,0	9,9	-8,8	15,0	3,2	4,8	14,6	25,5	27,0	12,4	10,7	1,6	9,8	10,9	33,0
	4	6650	-1	14,5	86,0	-0,5	3,5	-14,0	5,8	5,2	11,0	9,0	10,1	18,1	29,0	26,0	16,7	10,0	1,1	8,0	10,9	30,0
	5	4150	0,5	14,5	73,0	-0,5	3,0	-11,0	3,9	5,5	13,0	10,6	11,5	15,9	28,2	26,0	16,5	10,1	0,9	4,4	12,3	27,7
96119D	1	7440	-8,5	14,0	104,0	9,0	3,5	-10,5	10,3	-18,5	8,0	-4,3	0,1	12,8	28,4	30,0	10,7	4,2	4,4	12,7	15,6	36,9
23.08.-96	2	6780	-7,5	13,5	94,5	8,5	3,0	-14,5	8,0	-13,9	9,0	-4,2	-0,1	12,5	27,2	27,0	10,7	3,3	4,1	12,6	14,7	34,7
CNref60	3	8510	-7,0	17,5	111,0	9,0	3,5	-15,0	13,3	-11,5	15,0	1,8	4,3	15,6	28,3	31,0	13,5	8,8	2,5	11,3	12,7	35,3
	4	6970	-1	15,5	89,0	-0,5	3,5	-12,0	8,8	3,5	14,0	0,3	8,2	18,4	30,7	27,0	17,3	1,3	7,9	10,2	12,3	31,7
	5	4380	0,5	14,5	75,0	-0,5	3,0	-12,5	6,6	5,4	12,0	2,0	10,0	18,2	30,5	28,0	17,5	1,5	8,0	8,2	12,3	30,0
96120D	1	7040	-8,5	13,5	102,0	8,5	3,5	-10,0	10,0	-14,9	9,0	-5,3	-0,3	13,0	28,1	27,0	11,4	3,2	5,0	13,3	15,1	36,6
23.08.-96	2	6720	-7,0	13,5	93,0	9,5	3,5	-8,0	8,0	-17,6	10,0	-5,6	-1,1	12,6	27,6	27,0	10,6	1,4	4,5	13,7	15,0	34,6
CNref43	3	8710	-6,5	17,0	113,0	8,0	3,5	-15,0	14,0	-5,9	15,0	1,6	4,0	15,4	28,5	30,0	13,8	8,1	2,4	11,4	13,1	35,0
	4	6510	-0,5	15,5	86,0	0,0	3,0	-16,0	8,5	5,1	13,0	6,3	9,7	19,2	32,7	29,0	18,1	6,8	3,4	9,5	13,5	33,2
	5	4460	1	15,0	74,5	0,0	3,0	-12,0	6,4	4,4	15,0	7,5	11,8	17,1	33,0	29,0	18,3	6,5	4,3	5,3	15,9	32,0

AUDI 1.9 TDI, FTP results

	Temp. °C	FTP composite, g/km CO	HC	NOx	CO2	PM
CEC	16	0,090	0,037	0,625	185,940	0,090
CEC+ci	15	0,056	0,030	0,557	184,092	0,098
RME20	17	0,089	0,040	0,609	186,713	0,076
RME20+ci	16	0,079	0,024	0,608	184,479	0,081
EtRE	16	0,051	0,051	0,689	181,578	0,042
EtRE+ci	16	0,053	0,050	0,671	179,067	0,051
CEC	-6	0,158	0,059	0,631	207,612	0,117
CEC+ci	-6	0,127	0,044	0,542	201,362	0,107
RME20	-6	0,154	0,068	0,600	202,944	0,087
RME20+ci	-6	0,119	0,037	0,607	201,660	0,088
EtRE	-6	0,118	0,069	0,668	195,790	0,047
EtRE+ci	-6	0,085	0,050	0,628	195,164	0,057
CHANGE-%						
CEC->RME20, 16 °C		-2,0	10,1	-2,5	0,4	-14,9
CEC->RME20, -6 °C		-2,7	16,1	-4,9	-2,2	-25,8
CEC->EtRE, 16 °C		-43,2	38,7	10,2	-2,3	-52,7
CEC->EtRE, -6 °C		-25,3	17,6	5,8	-5,7	-59,6
CEC->CEC+ci, 16 °C		-37,7	-18,0	-10,8	-1,0	9,7
CEC->CEC+ci, -6 °C		-19,9	-25,6	-14,1	-3,0	-8,0
RME20->RME20+ci, 16 °C		-10,4	-40,1	-0,2	-1,2	6,6
RME20->RME20+ci, -6 °C		-22,6	-45,5	1,1	-0,6	1,2
EtRE->EtRE+ci, 16 °C		2,2	-1,1	-2,6	-1,4	20,0
EtRE->EtRE+ci, -6 °C		-27,8	-27,0	-6,0	-0,3	20,1

	Temp. °C	CO, FTP phases, g/km Bag 1	Bag 2	Bag 3	HC, FTP phases, g/km Bag 1	Bag 2	Bag 3
CEC	16	0,217	0,041	0,087	0,052	0,034	0,030
CEC+ci	15	0,176	0,015	0,045	0,048	0,029	0,019
RME20	17	0,222	0,044	0,072	0,046	0,045	0,027
RME20+ci	16	0,184	0,043	0,069	0,039	0,022	0,018
EtRE	16	0,157	0,015	0,040	0,057	0,054	0,041
EtRE+ci	16	0,133	0,029	0,036	0,050	0,055	0,042
CEC	-6	0,449	0,070	0,106	0,120	0,047	0,035
CEC+ci	-6	0,341	0,057	0,097	0,079	0,037	0,029
RME20	-6	0,408	0,072	0,117	0,111	0,066	0,039
RME20+ci	-6	0,326	0,053	0,089	0,070	0,031	0,024
EtRE	-6	0,376	0,031	0,088	0,106	0,062	0,054
EtRE+ci	-6	0,274	0,022	0,063	0,081	0,044	0,040
CHANGE-%							
CEC->RME20, 16 °C		2,1	6,0	-17,0	-12,1	33,1	-9,7
CEC->RME20, -6 °C		-9,1	3,2	10,4	-7,8	42,1	12,1
CEC->EtRE, 16 °C		-27,6	-64,2	-54,0	8,8	58,5	36,0
CEC->EtRE, -6 °C		-16,2	-55,2	-16,5	-12,0	33,1	54,9
CEC->CEC+ci, 16 °C		-19,2	-64,3	-48,6	-9,3	-14,3	-37,7
CEC->CEC+ci, -6 °C		-24,1	-19,0	-8,1	-34,4	-20,4	-16,6
RME20->RME20+ci, 16 °C		-17,0	-2,6	-4,1	-15,3	-52,2	-34,2
RME20->RME20+ci, -6 °C		-20,1	-27,0	-23,5	-36,8	-53,1	-39,6
EtRE->EtRE+ci, 16 °C		-15,5	95,7	-10,0	-12,3	2,0	3,2
EtRE->EtRE+ci, -6 °C		-27,2	-29,9	-28,9	-23,3	-30,0	-26,1

	Temp. °C	NOx, FTP phases, g/km Bag 1	Bag 2	Bag 3	PM, FTP phases, g/km Bag 1	Bag 2	Bag 3
CEC	16	0,701	0,618	0,581	0,092	0,092	0,084
CEC+ci	15	0,616	0,547	0,532	0,104	0,099	0,093
RME20	17	0,691	0,597	0,570	0,082	0,076	0,074
RME20+ci	16	0,688	0,580	0,601	0,086	0,082	0,077
EtRE	16	0,787	0,667	0,657	0,048	0,041	0,041
EtRE+ci	16	0,748	0,647	0,659	0,057	0,051	0,046
CEC	-6	0,824	0,600	0,545	0,137	0,116	0,103
CEC+ci	-6	0,740	0,505	0,462	0,123	0,105	0,101
RME20	-6	0,784	0,570	0,520	0,104	0,083	0,081
RME20+ci	-6	0,819	0,559	0,537	0,104	0,084	0,082
EtRE	-6	0,856	0,634	0,590	0,068	0,041	0,044
EtRE+ci	-6	0,840	0,581	0,555	0,071	0,054	0,051
CHANGE-%							
CEC->RME20, 16 °C		-1,5	-3,4	-1,8	-11,0	-17,8	-12,1
CEC->RME20, -6 °C		-4,8	-5,0	-4,6	-24,5	-28,8	-20,8
CEC->EtRE, 16 °C		12,2	7,9	13,1	-47,7	-55,8	-50,4
CEC->EtRE, -6 °C		3,9	5,7	8,2	-50,3	-65,1	-57,4
CEC->CEC+ci, 16 °C		-12,2	-11,4	-8,4	12,9	7,5	11,8
CEC->CEC+ci, -6 °C		-10,1	-15,8	-15,2	-10,7	-9,8	-1,4
RME20->RME20+ci, 16 °C		-0,4	-2,9	5,4	5,4	7,9	4,9
RME20->RME20+ci, -6 °C		4,5	-1,8	3,3	0,4	2,0	0,3
EtRE->EtRE+ci, 16 °C		-4,9	-3,0	0,3	18,8	24,9	11,9
EtRE->EtRE+ci, -6 °C		-1,9	-8,3	-5,9	4,6	32,9	16,0