**JOWA GERMANY GmbH**

# Investigations of the compatibility of sulphur-poor fuels (Sulphur part smaller 10 ppm), where appropriate with bio components at older in operation contained engines in inland navigation

Final report

FE project Nr.30.0331/2007
Bundesministerium für Verkehr, Bau und Stadtentwicklung

**Client:**

Bundesministerium für Verkehr, Bau und Stadtentwicklung
Referat WS26
Robert – Schuman – Platz 1, 53175 Bonn

**Head of project:**

Bundesministerium für Verkehr, Bau und Stadtentwicklung
Referat WS26
Robert – Schuman – Platz 1, 53175 Bonn
Dipl.-Ing. W. Kliche

**Autor:**

JOWA GERMANY GmbH
Dr. - Ing. R. Moeck

Hohen Luckow, 08 / 2007

## Contents

## 1. Introduction

The present study is divided into three sections which are discussed with close reference to each other. In section 1, the available database on the engine technology, respectively combustion systems of German inland navigation vessels are analysed and qualified concerning age, development status and performance parameters.

Section 2 describes properties and basic conditions for the application of low sulphur or sulphur free fuels compared with the marine gasoil qualities presently in use. Furthermore, it presents major findings relevant for the use of bio components in diesel fuel.

In Section 3, the findings for fuel qualities presented in section 2 are examined in relation to engine, respectively combustion technology conditions on board as derived in section 1.

Conclusions about the safe, environmentally friendly operation of inland marine engines and for the storage and application of marine fuels are drawn and consequences and recommendations for the operation, maintenance and servicing of engines and boiler plants are given.

## 2. Ageing and performance structure of the energy systems applied in inland navigation

In order to assess fuel compatibility of older engines, an analysis of driving engines used in inland water transport is made with the aim to select a number of engine types and their manufacturers for being exemplary of such engines. This serves as the basis for the generalisation of statements on the fuel compatibility of the drive engines as well as construction types and fuel compatibility of fuel systems and fuel injection units. Furthermore, the gas oil compatibility of on-board boiler plants and auxiliary drives is to be considered since the various energy systems installed on inland navigation vessels are all fired with the same sort of fuel.

As for main engines, a database prepared in the study “Establishing techniques for the determination of air pollution emissions of running inland navigation vessels“ [1] can be employed, whereas there are hardly any reliable data on heating systems and auxiliary drives available.

### 2.1 Diesel engines – main engine

To serve the objective of this study, the manufacturers of the engines most widely applied in the German inland navigation were selected from the existing database. The data are prepared up to the year 2000 and comprise complete details on about 71 % of the engines. It is assumed that they reflect the current situation in the application of older engines in inland water transport. From diagram 2.1, 6 engine manufacturers which are represented with the engine types depicted in diagrams 2.2 – 2.15 (table 2.1) have been derived. Amongst the older engines, preferably marine engines are applied as main engine. As diesel engine auxiliary drives for generators, bow thrusters, pumps and winches, however, modified engines of commercial vehicles and engines of low power have been used.. The smallest main engine power in the data basis is 130 kW, the biggest 2 650 kW. The engine speed range of the engines in the study varies from 300 to 3 900 revs per hour , thus lying within the range of medium fast and fast running engines.

Diagram 2.1 shows that older engines in use have predominantly been engines of German engine manufacturers such as Deutz, MAN, MWM, SKL. The term “older engines” is used in this study with reference to engines that were installed aboard inland navigation vessels up to the ‘80s.

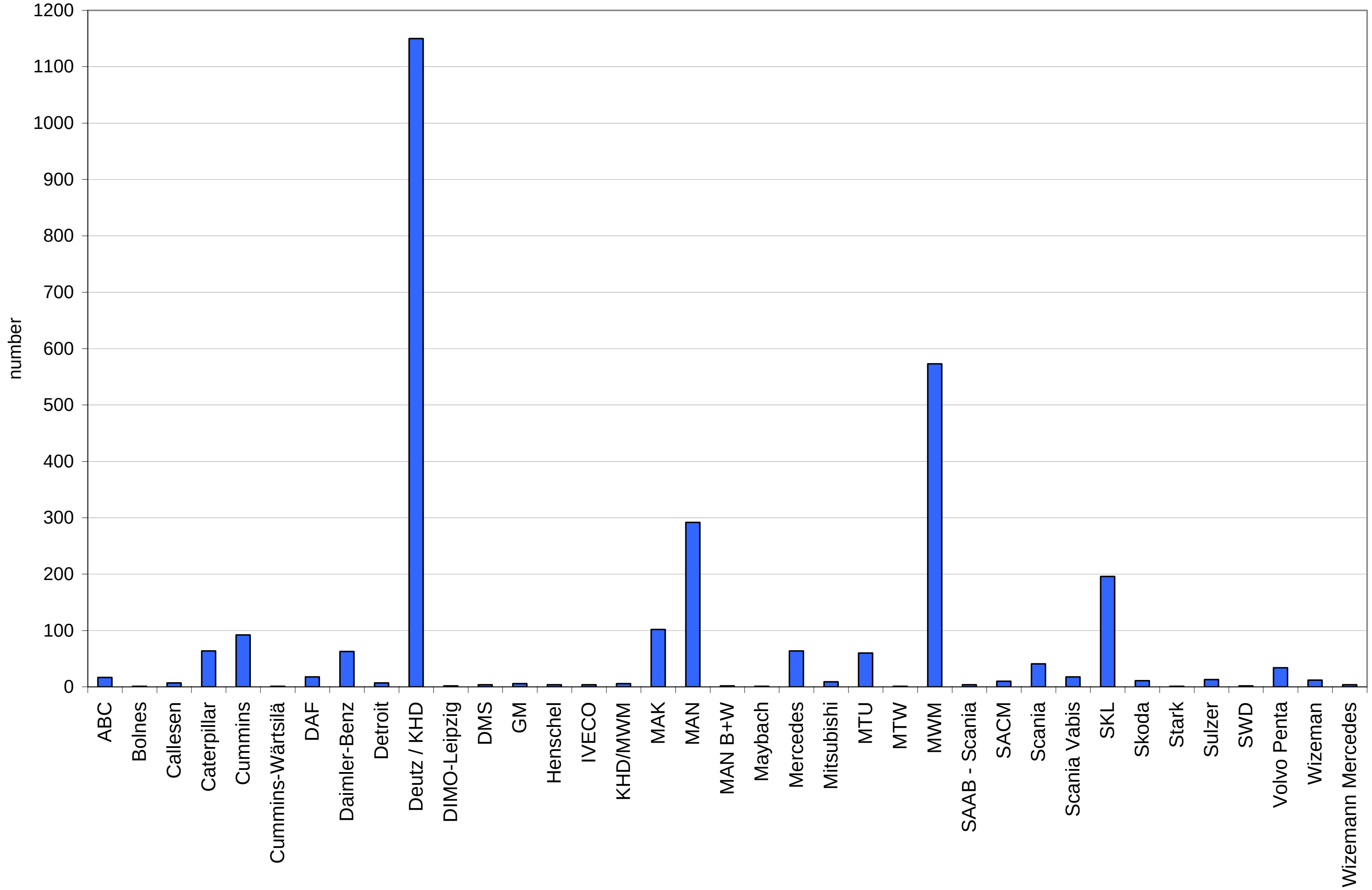



diagram 2.1: diesel engines applied in German inland navigation until 2000 [1]

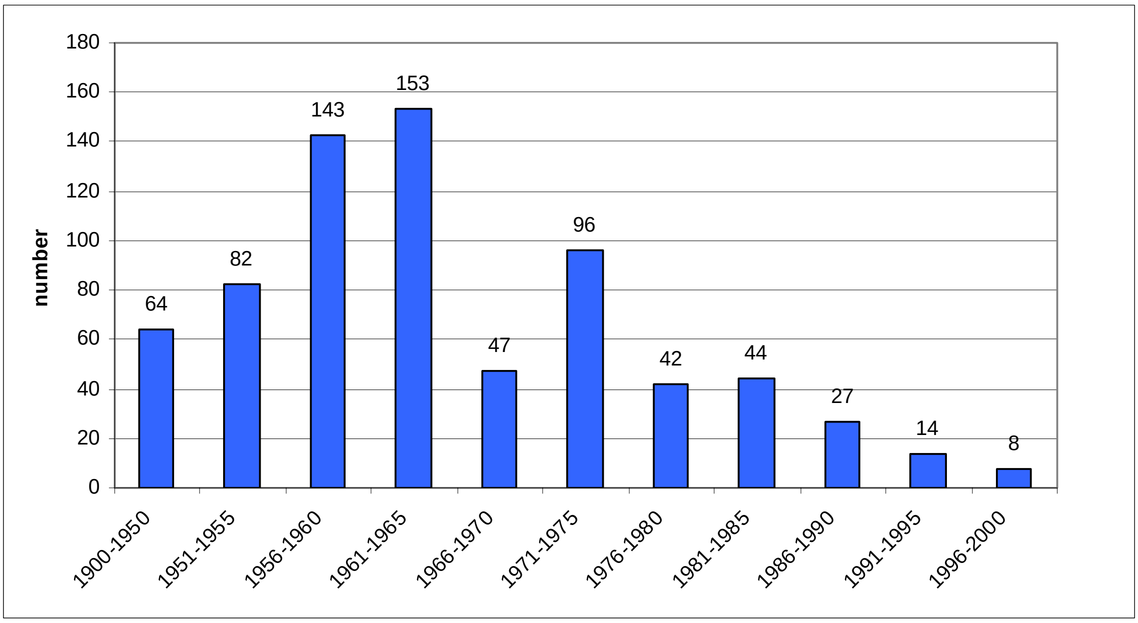
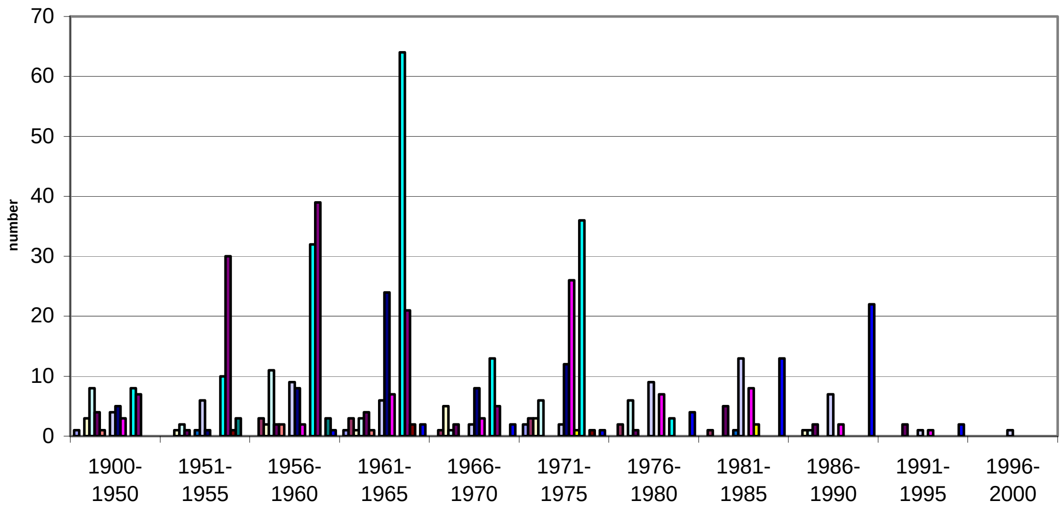



diagram 2.2: number of engines DEUTZ / KHD by delivery period [1]




| | 1900-1950 | 1951-1955 | 1956-1960 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | 1981-1985 | 1986-1990 | 1991-1995 | 1996-2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| F M 716 | 1 | | | 1 | | 2 | | | | | |
| BF M 716 | | | 3 | 3 | 1 | 3 | 2 | 1 | | | |
| SF M 716 | 3 | 1 | 2 | 1 | 5 | 3 | | | 1 | | |
| SBF M 716 | 8 | 2 | 11 | 3 | 1 | 6 | 6 | | 1 | | |
| BA M 816 | 4 | 1 | 2 | 4 | 2 | | 1 | 5 | 2 | 2 | |
| KDH 816 | 1 | | 2 | 1 | | | | | | | |
| SA M 816 | | 1 | | | | | | 1 | | | |
| SBA M 816 | 4 | 6 | 9 | 6 | 2 | 2 | 9 | 13 | 7 | 1 | 1 |
| RBA M 528 | 5 | 1 | 8 | 24 | 8 | 12 | | | | | |
| SBA M 528 | 3 | | 2 | 7 | 3 | 26 | 7 | 8 | 2 | 1 | |
| BA M 528 | | | | | | 1 | | 2 | | | |
| RBV M 545 | 8 | 10 | 32 | 64 | 13 | 36 | 3 | | | | |
| RV M 545 | 7 | 30 | 39 | 21 | 5 | | | | | | |
| BV M 545 | | 1 | | 2 | | 1 | | | | | |
| SBV M 545 | | 3 | 3 | | | | | | | | |
| SBV M 628 | | | 1 | 2 | 2 | 1 | 4 | 13 | 22 | 2 | |

diagram 2.3: number of engines DEUTZ / KHD by type and delivery period [1]

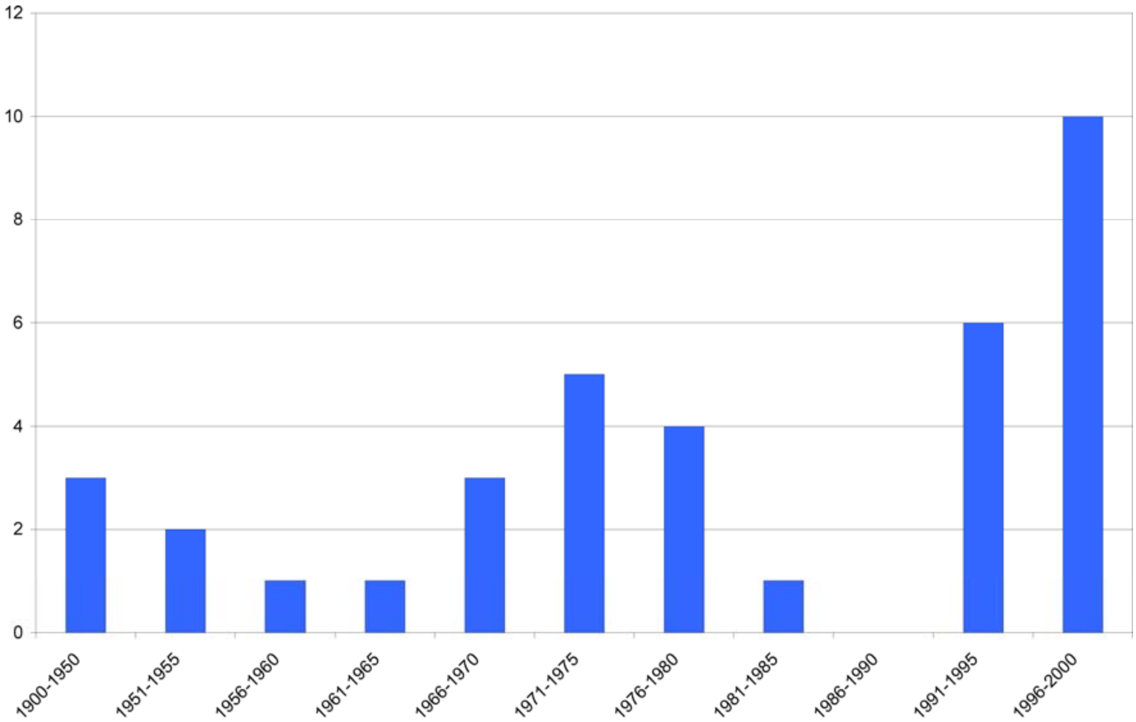
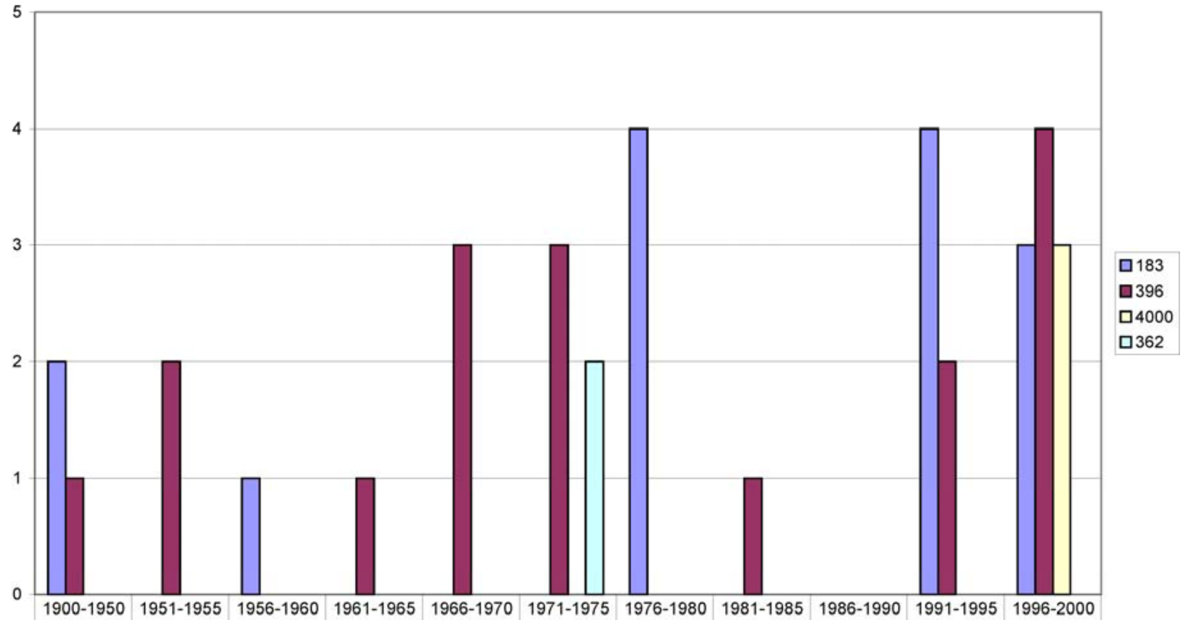



diagram 2.4: number of engines  MTU by delivery period [1]




| | 1900-1950 | 1951-1955 | 1956-1960 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | 1981-1985 | 1986-1990 | 1991-1995 | 1996-2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 183 | 2 | | 1 | | | | 4 | | | 4 | 3 |
| 396 | 1 | 2 | | 1 | 3 | 3 | | 1 | | 2 | 4 |
| 4000 | | | | | | | | | | | 3 |
| 362 | | | | | | 2 | | | | | |

diagram 2.5: number of engines MTU by type and delivery period [1]

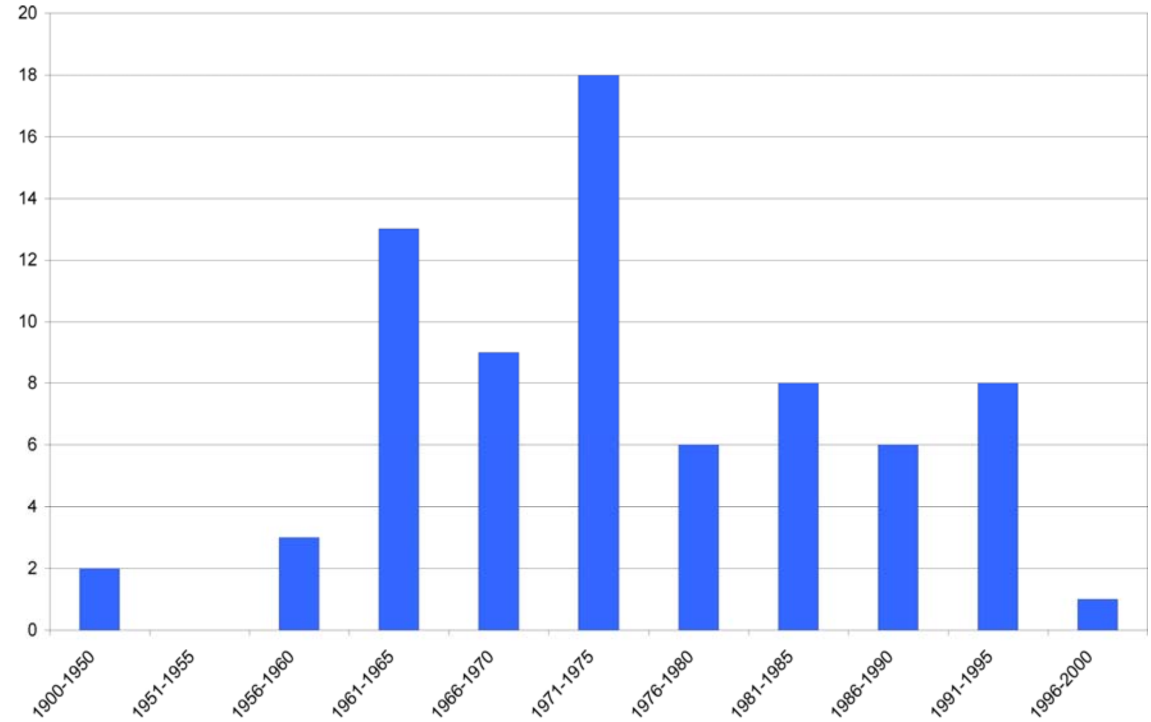
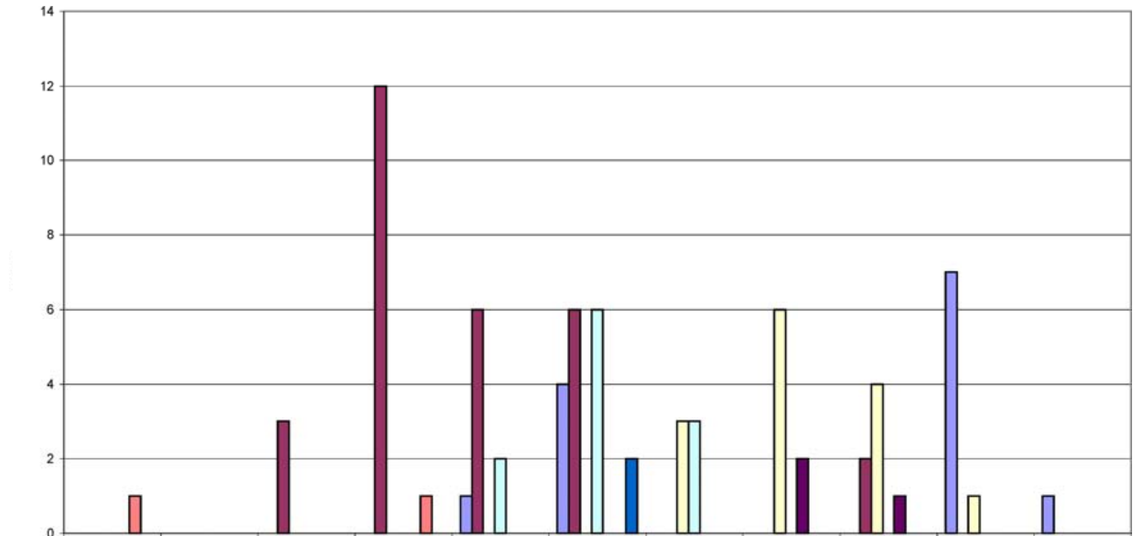



diagram 2.6: number of engines MAK by delivery period [1]




| | 1900-1950 | 1951-1955 | 1956-1960 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | 1981-1985 | 1986-1990 | 1991-1995 | 1996-2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M 20 | | | | | 1 | 4 | | | | 7 | 1 |
| M 451 | | | 3 | 12 | 6 | 6 | | | 2 | | |
| M 452 | | | | | | | 3 | 6 | 4 | 1 | |
| M 281 | | | | | 2 | 6 | 3 | | | | |
| M 332 | | | | | | | | 2 | 1 | | |
| M 351 | 1 | | | 1 | | | | | | | |
| M 282 | | | | | | 2 | | | | | |

diagram 2.7: number of engines MAK by type and delivery period [1]

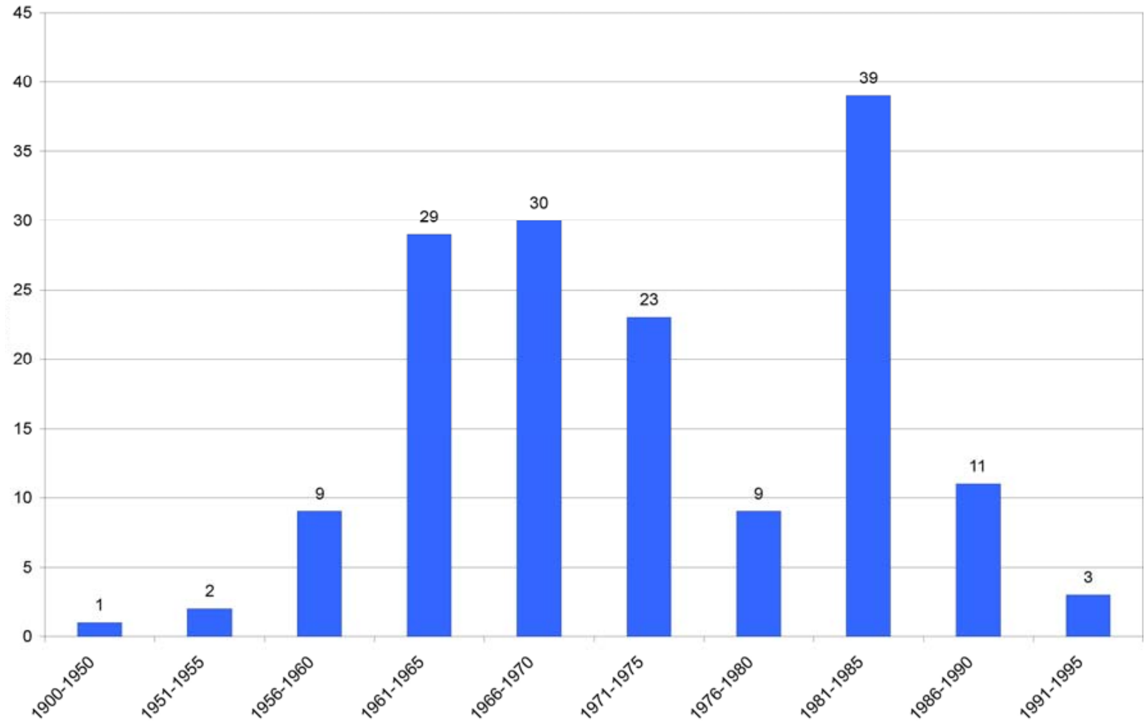
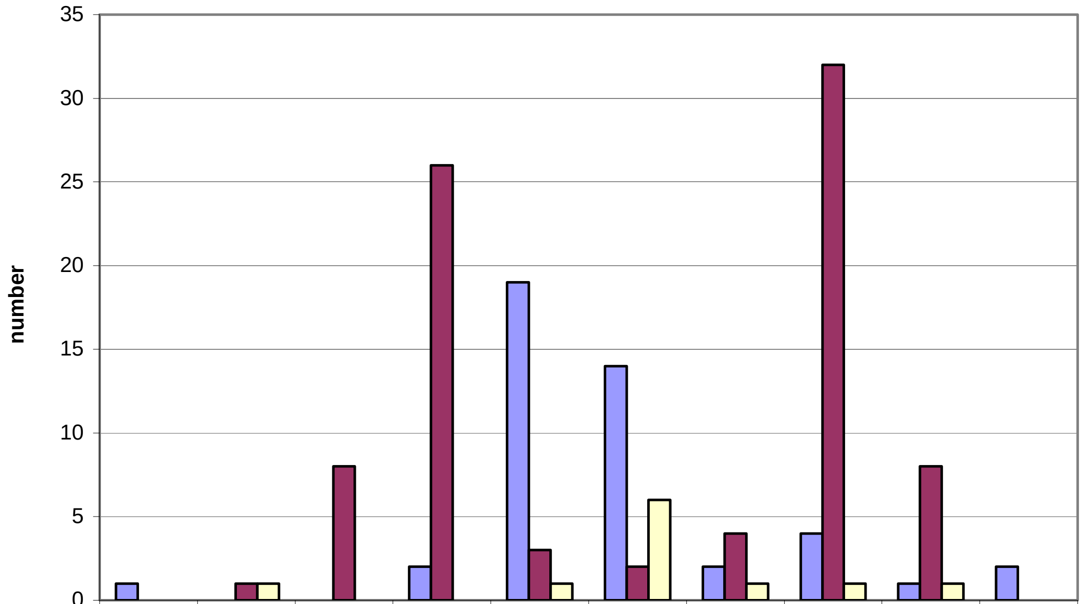



diagram 2.8: number of engines SKL by delivery period [1]




| | 1900-1950 | 1951-1955 | 1956-1960 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | 1981-1985 | 1986-1990 | 1991-1995 |
|---|---|---|---|---|---|---|---|---|---|---|
| NVD 26 | 1 | | | 2 | 19 | 14 | 2 | 4 | 1 | 2 |
| NVD 36 | 0 | 1 | 8 | 26 | 3 | 2 | 4 | 32 | 8 | 0 |
| NVD 48 | 0 | 1 | 0 | 0 | 1 | 6 | 1 | 1 | 1 | 0 |

diagram 2.9: number of engines SKL by type and delivery period [1]

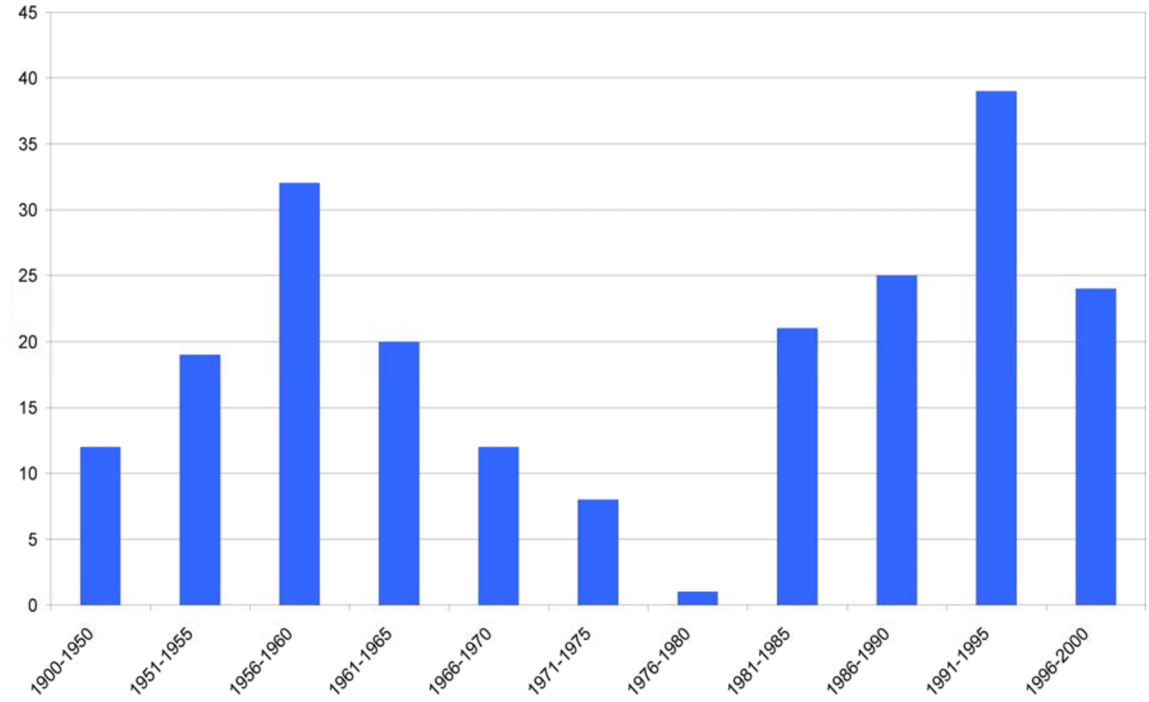
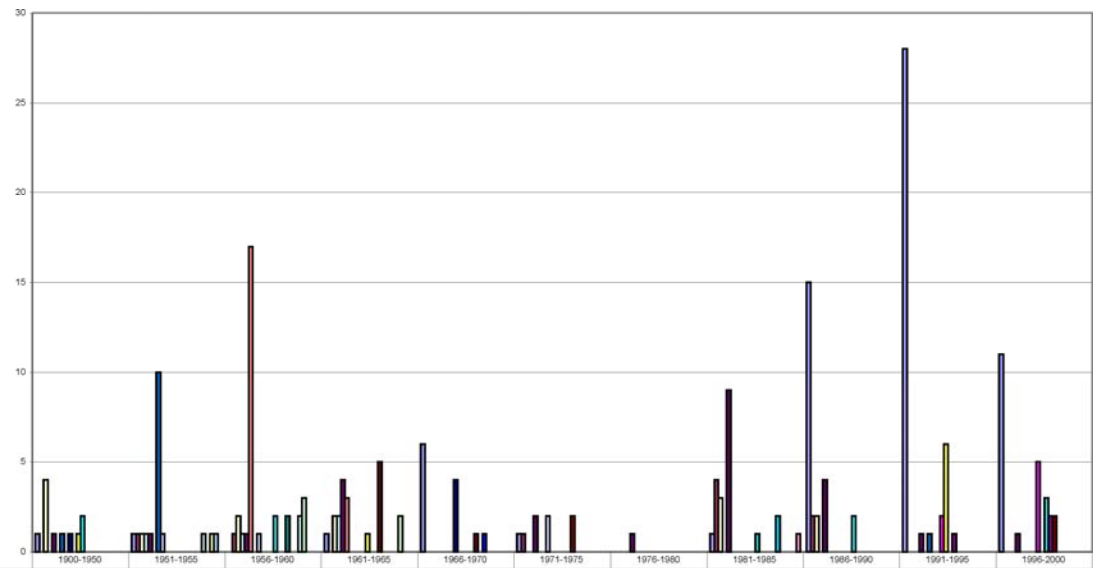



diagram 2.10: number of engines MAN by delivery period [1]




| | 1900-1950 | 1951-1955 | 1956-1960 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | 1981-1985 | 1986-1990 | 1991-1995 | 1996-2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D2866 | 1 | 1 | | 1 | 6 | 1 | | 1 | 15 | 28 | 11 |
| D2530 ME | | 1 | 1 | | | 1 | | 4 | 2 | | |
| D2542 ME | 4 | 1 | 2 | 2 | | | | 3 | 2 | | |
| D2556 MTE | | 1 | 1 | 2 | | | | | | | |
| D2566 M | 1 | 1 | 1 | 4 | | 2 | 1 | 9 | 4 | 1 | 1 |
| G6 V30/45 | | | 17 | 3 | | | | | | | |
| G6 V42 | 1 | 10 | | | | | | | | 1 | |
| 2156 HM | | 1 | 1 | | | 2 | | | | | |
| D2148 M | 1 | | | | 4 | | | | | | |
| D2848 LE | | | | | | | | | | 2 | 5 |
| D2840 LE | 1 | | | 1 | | | | | | 6 | |
| D2842 LE | 2 | | 2 | | | | | 1 | 2 | | 3 |
| D0226 MLE | | | | | | | | | | 1 | 2 |
| R8 V16/18 T | | | | 5 | 1 | 2 | | | | | 2 |
| 6VW 17,5/22 | | | 2 | | | | | | | | |
| D2658 M | | | | | 1 | | | | | | |
| MTE 253 30 | | | | | | | | 2 | | | |
| W8 V17,5/22A | | 1 | 2 | | | | | | | | |
| G6 V23,5/33 | | | 3 | 2 | | | | | | | |
| G6V 29/42 | | 1 | | | | | | | | | |
| G6V 28/51 | | 1 | | | | | | | | | |
| G6V135/33 | | | | | | | | 1 | | | |

diagram 2.11: number of engines MAN by type and delivery period [1]

JOWA GERMANY GmbH • Bützower Str. 1a • 18239 Hohen Luckow
Tel. 038295 / 74115 • Fax. 038295 / 74141• email info@jowa.de

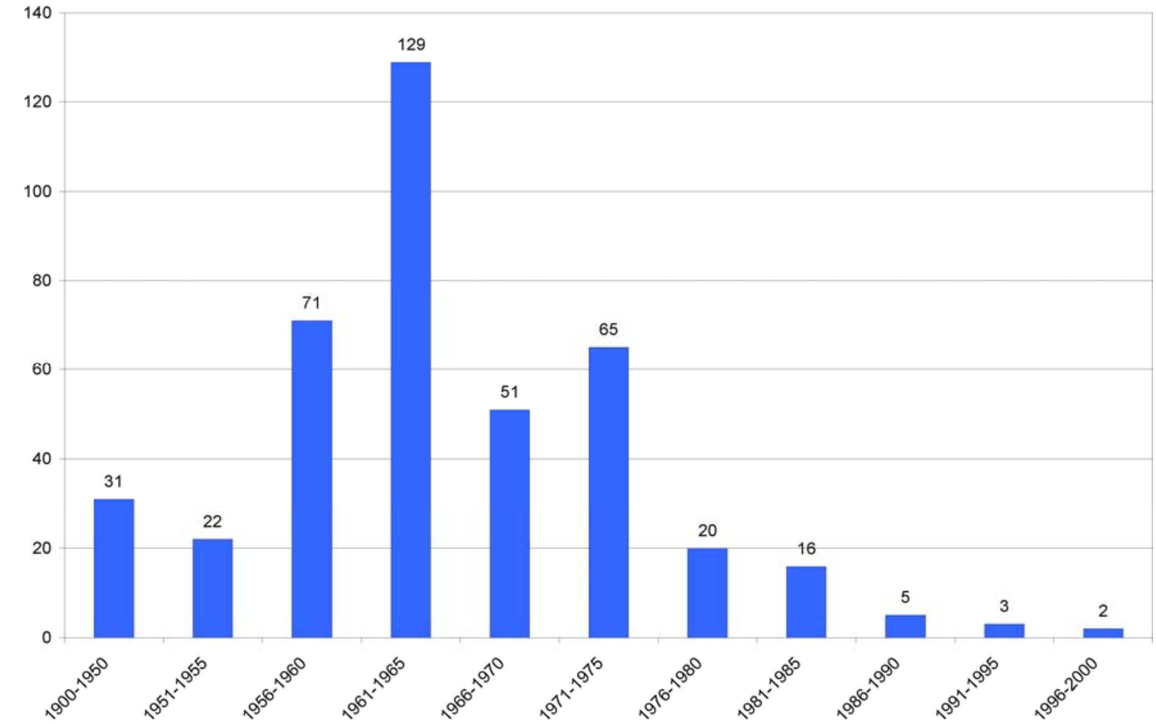
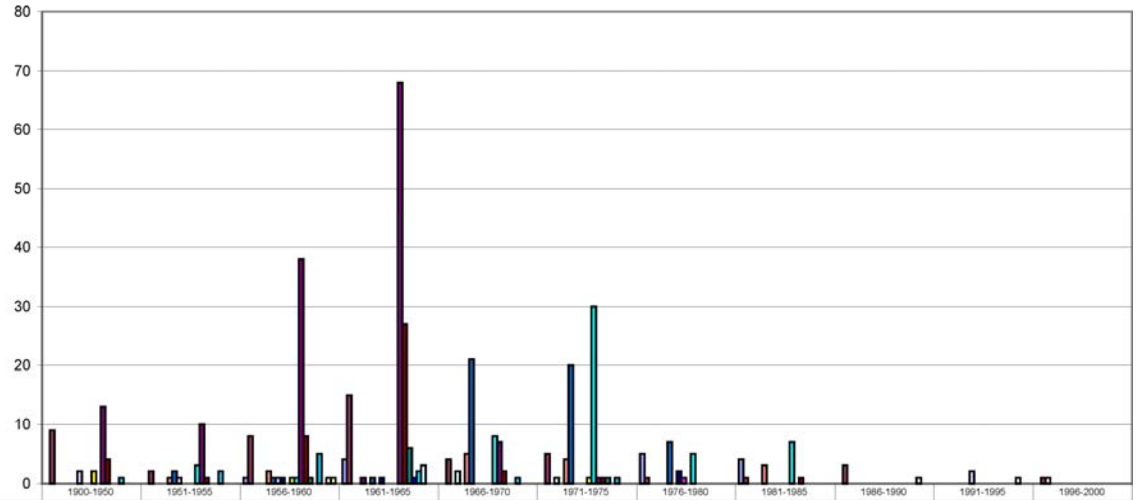



diagram 2.12: number of engines MWM by delivery period [1]




| | 1900-1950 | 1951-1955 | 1956-1960 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | 1981-1985 | 1986-1990 | 1991-1995 | 1996-2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D 232 | | | 1 | 4 | | | 5 | 4 | | | |
| RHS 518 | 9 | 2 | 8 | 15 | 4 | 5 | 1 | 1 | 3 | | 1 |
| 440K6 | | | | | | | | | | | 1 |
| 12 RS 18/22 | | | | | 2 | 1 | | | | | |
| D 434-6 U | | | | 1 | | | | | | | |
| D 440-06 | | 1 | 2 | | 5 | 4 | | 3 | | | |
| D 484 | | 2 | 1 | 1 | 21 | 20 | 7 | | | | |
| D 601 | 2 | 1 | 1 | | | | | | | 2 | |
| D 602 V 12 | | | 1 | 1 | | | 2 | | | | |
| TBD 603-V12 | | | | | | | 1 | | | | |
| D 604 BL 6 | 2 | | 1 | | | 1 | | | | | |
| DT 440-6 | | 3 | 1 | | 8 | 30 | 5 | 7 | | | |
| R H 348 SU | 13 | 10 | 38 | 68 | 7 | 1 | | | | | |
| R.H. 435 SU | 4 | 1 | 8 | 27 | 2 | 1 | | 1 | | | |
| RH 330 S | | | 1 | 6 | | 1 | | | | | |
| RBV 6M 545 | | | | 1 | | | | | | | |
| RHS 526 S | 1 | 2 | 5 | 2 | 1 | 1 | | | | | |
| TBD 234 | | | | 3 | | | | | 1 | 1 | |
| TRH 445 SU | | | 1 | | | | | | | | |

diagram 2.13: number of engines MWM by type and delivery period [1]

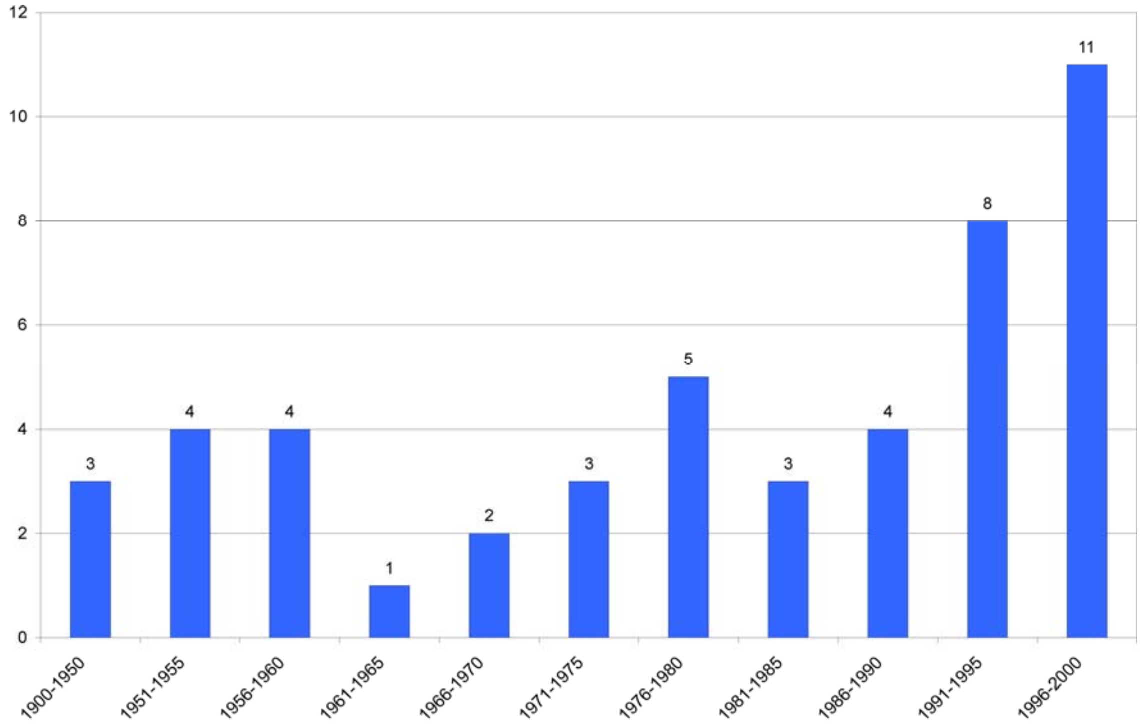



diagram .14: number of engines Caterpillar by delivery period [1]

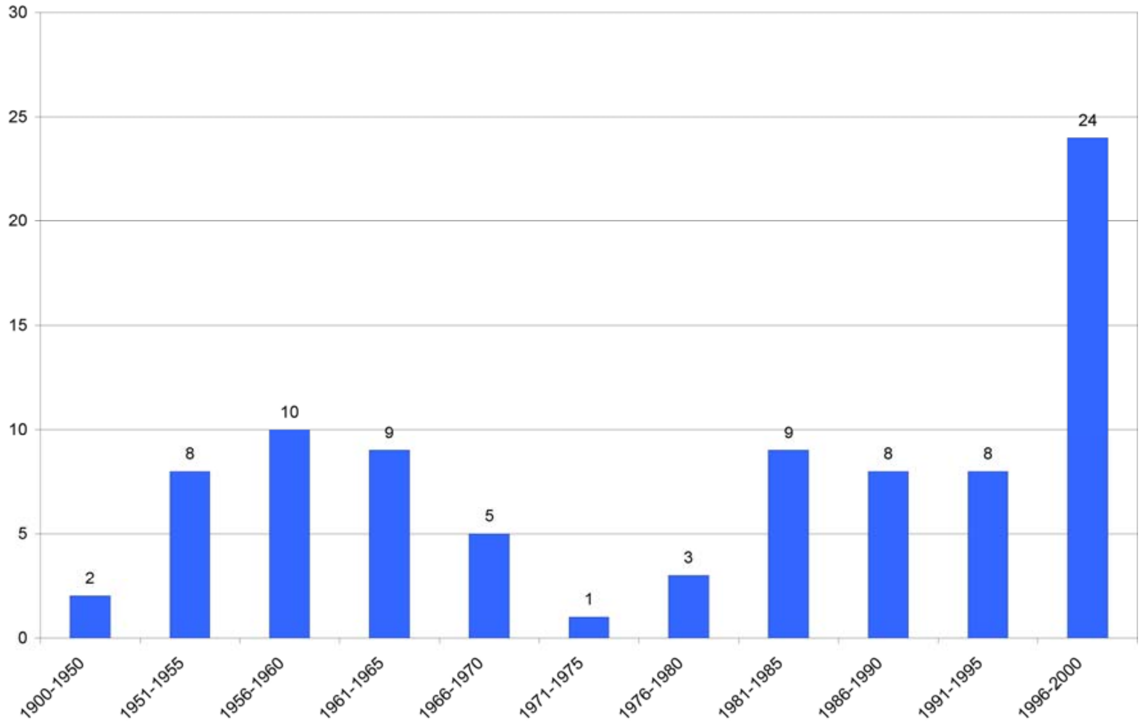



diagram 2.15: number of engines Cummins by delivery period [1]

table 2.1: engine types in use and selected performance parameters [1]

| Manufacturer | type of engine | number of engines | bore / stroke [mm] | pe [bar] | cylinder power [kW] | rev [min-1] | power [kW] |
|---|---|---|---|---|---|---|---|
| **MAN** | D 2866 | 65 | 128 / 155 | 7,24 - 19,05 | 21,67 - 56,67 | 1500 - 2200 | 130 - 340 |
| (212) | D 2566 | 25 | 125 / 155 | 7,31 -- 12,91 | 21,67 - 36,83 | 1500 - 2200 | 130 - 221 |
| | GV 30/45 | 20 | 300 / 450 | 5,78 - 10,30 | 61,33 - 109,17 | 350 - 400 | 368 - 699 |
| | GV 42 | 12 | 290 / 420 | 4,96 - 11,53 | 46 - 100 | 375 - 380 | 368 - 600 |
| **DEUTZ** | M 545 | 276 | 321 /451 | 4,84 - 21,86 | 55,17 - 133,33 | 330 - 392 | 331 - 1000 |
| (761) | M 528 | 120 | 220 / 280 | 2,48 - 36,51 | 35,88 - 133,33 | 350 - 900 | 287 - 1001 |
| | M 716 | 70 | 135 / 160 | 1,33 - 22,28 | 17,17 - 72,50 | 1000 - 1800 | 147 - 662 |
| | M 628 | 46 | 240 / 280 | 11,62 - 25,58 | 98,0 - 217,33 | 500 - 1032 | 588 - 1304 |
| **SKL** | 6 NVD 26 | 45 | 180 / 260 | 5,36 - 17,73 | 22,17 - 73,33 | 750 - 1000 | 133 - 440 |
| (156) | NVD 36 | 78 | 240 / 360 | 4,52 - 10,81 | 26,67 - 55,00 | 340 - 600 | 160 - 425 |
| | NVD 48 | 11 | 320 - 480 | 6,26 - 10,55 | 80,5 - 121,38 | 350 - 428 | 483 - 971 |
| **MWM** | RHS 518 | 49 | 136-140 / 180 | 5,75 - 12,24 | 16,13 - 40,0 | 1000 - 1950 | 138 - 361 |
| (413) | DT 440 | 70 | 230 / 270 | 3,39 - 16,05 | 41,67 - 135 | 700 - 900 | 250 - 1080 |
| | RH 348 | 137 | 320 / 480 | 3,81 - 11,05 | 51,50 - 133,33 | 325 - 375 | 309 - 850 |
| | RH 435 | 45 | 250 / 350 | 5,98 - 9,94 | 32,5 - 78,5 | 375 - 640 | 195 - 626 |
| **MAK** | M 451 | 29 | 320 / 450 | 5,97 - 13,56 | 67,5 - 147,17 | 300 - 380 | 405 - 883 |
| (74) | M 452 | 14 | 320 / 450 | 12,97 - 13,01 | 146,67 - 147,17 | 375 | 880 - 883 |
| | M 281 | 11 | 240 / 280 | 9,31 - 12,77 | 73,67 - 101,13 | 650 - 750 | 442 - 809 |
| | M 20 | 13 | 200 / 300 | 16,98 - 24,05 | 120,0 - 170,0 | 900 - 1000 | 720 - 1360 |
| **MTU** | 183 | 14 | 128 / 142 | 6,69 - 19,56 | 18,38 - 61,83 | 1500 - 2300 | 147 - 735 |
| (36) | 396 | 17 | 165 / 185 | 11,63 - 19,96 | 66,17 - 125,0 | 1500 - 1950 | 440 - 1500 |

The 21 engine types listed in table 2.1 cover ca. 80 % (which is 1 652 engines) of the 2 065 main engines of those completely described in the employed database of the German inland water transport within a power range from 130 kW up. This means a share of ca. 60 % of the total stock of main engines (2 897 engines) in 2000.

Exchanged engines and engines which have been placed into service later than in 2000 are classified as new engines. Corresponding with the development within the fleet of inland navigation vessels, engines of higher power (> 1500 kW) have been installed principally since the early ‘90s. They are not subject of the following examination for older engines.

## 2.2 Auxiliary drives -. diesel engines

Auxiliary drives have been applied on inland navigation vessels predominantly for

- bow thrusters,
- generators,
- pumps and for
- winch drives.

Auxiliary drives have not been covered in the database used in chapter 2.1. Their data are contained in the ZSUK (Zentralstelle Schiffsuntersuchungskommission) register of shipping. A first appraisal renders the available data of ZSUK inappropriate for project-related analysis. This can be put down firstly, to an incomplete and for objective reasons partly erroneous collecting of data and secondly, to the difficulties in checking the plausibility of data due to the multitude of possible engine types and manufacturers. Engine types and performance parameters have partly not been registered. It would have been essential for this project to estimate the age of the engines, which however is impossible to achieve as year of manufacture and year of the latest noise measurement were not separated when the data were captured.

The data found for medium installed power engines for bow thrusters and for process pumps, which are presented below, correspond with the power of small main engines. Diesel generators and winch engines are incomparable with main drive engines because of their small installed capacities. Major differences between main and auxiliary engines lie in the fuels used and the fuel injection systems. They are explained in chapter 4.

For further work it is assumed that despite of the above, the findings on the fuel compatibility of the engines presented in chapter 4 provide a suitable basis from which consequences and recommendations for the operation, maintenance and servicing of the main and auxiliary engines in use in the German inland navigation can be deduced.

<u>Lateral thrust unit</u>

According to the current ZSUK shipping register, there are ca. 790 vessels equipped with bow thrusters with direct diesel engine drives in the German inland water transport.

Diagrams 2.16 and 2.17 show that principally DAF engines are applied. Their medium installed power is ca. 210 kW.

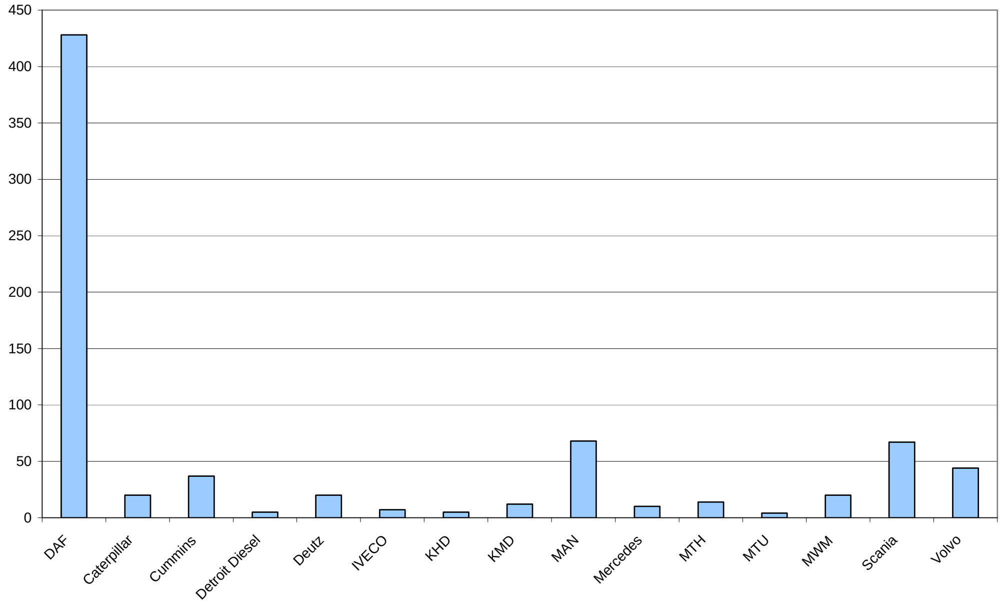



diagram 2.16: bow thrusters – diesel engines in German inland navigation [1]

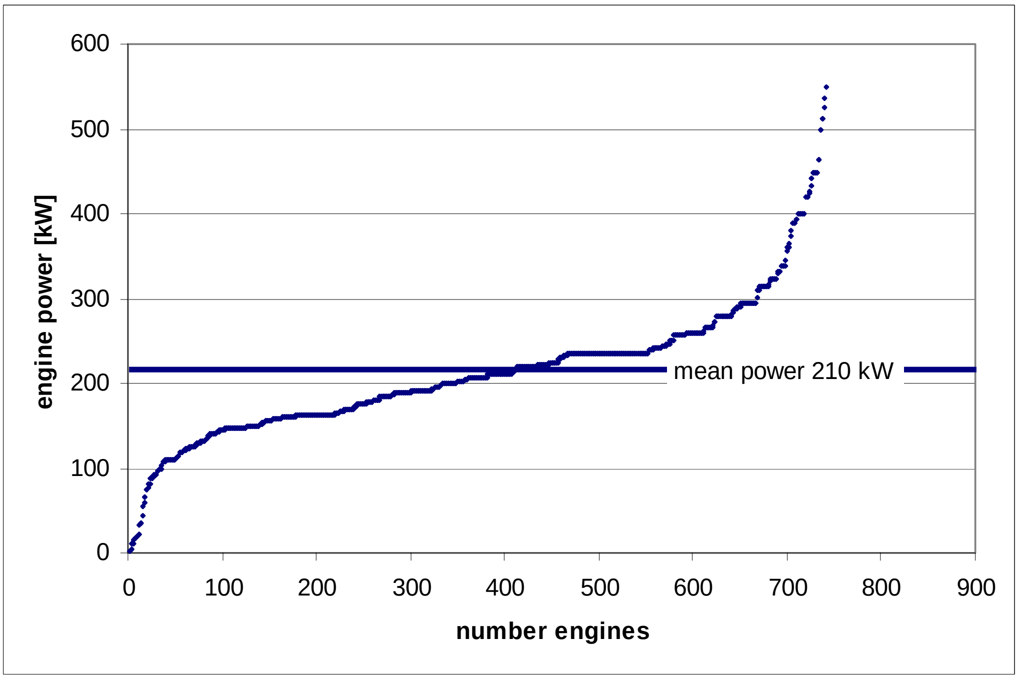



diagram 2.17:installed engine power of bow thrusters – diesel engines [1]

Process pumps

In the German inland navigation, loading and unloading pumps are nearly exclusively used on tankers. On the ZSUK shipping register there are ca. 290 pumps with direct diesel engine drives. The medium installed power of the engines is ca. 110 kW (diagrams 2.18; 2.19)

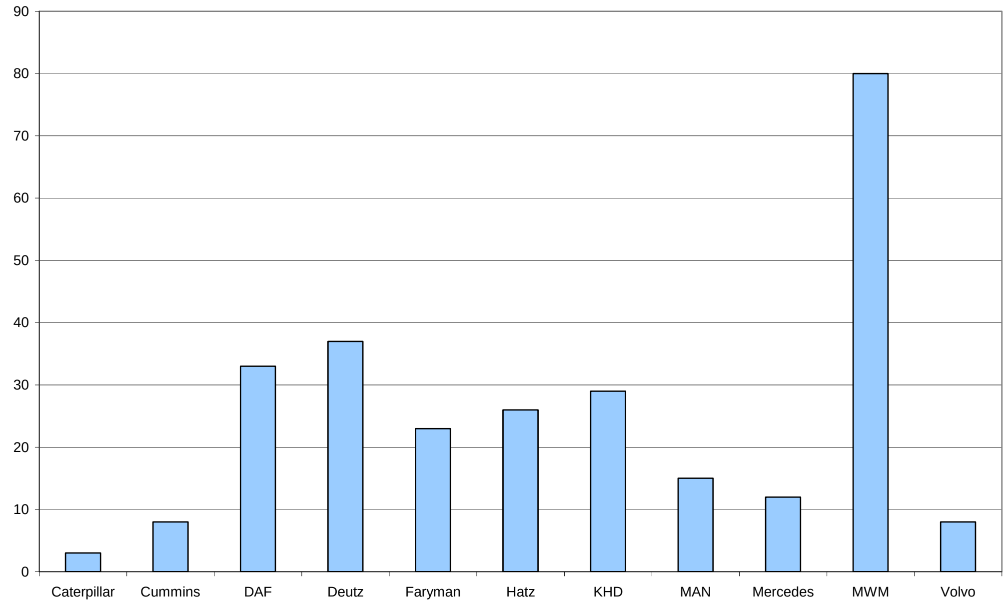



diagram 2.18: process pumps - diesel engines in German inland navigation [1]

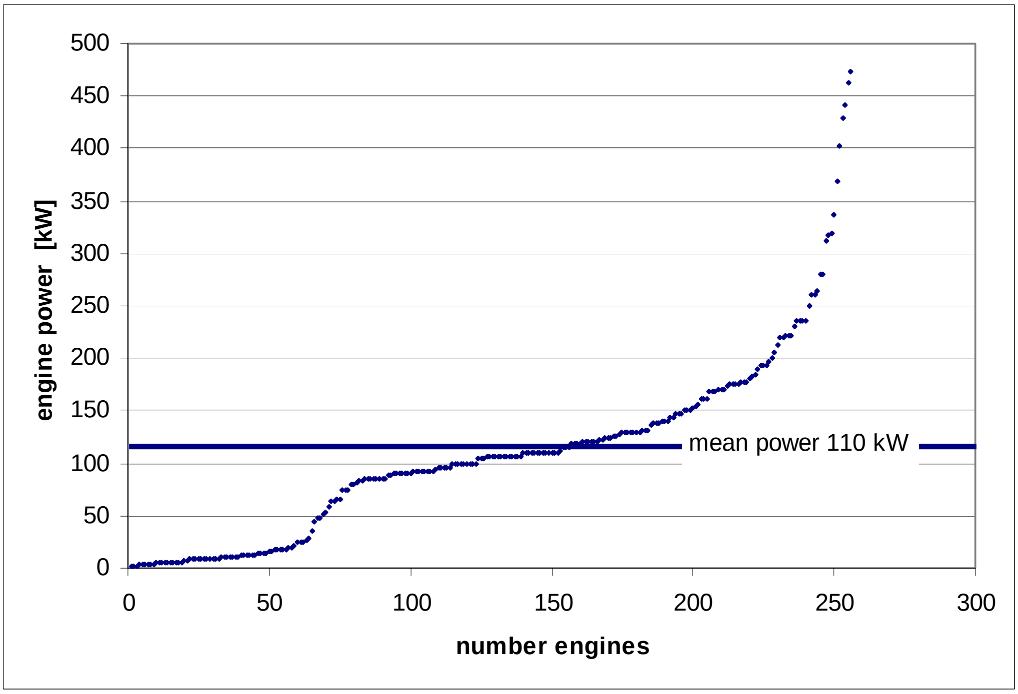



diagram .2.19: installed engine power of the process pumps – diesel engines [1]

Generator plants

From diagram 2.20 can be inferred that the majority of the ca. 2 350 generator plants registered with ZSUK are engines of the manufacturers Deutz and Hatz.. The medium installed power of the diesel generators applied on board inland navigation vessels for the generation of electricity is ca. 47,5 kW (diagram 2.21).

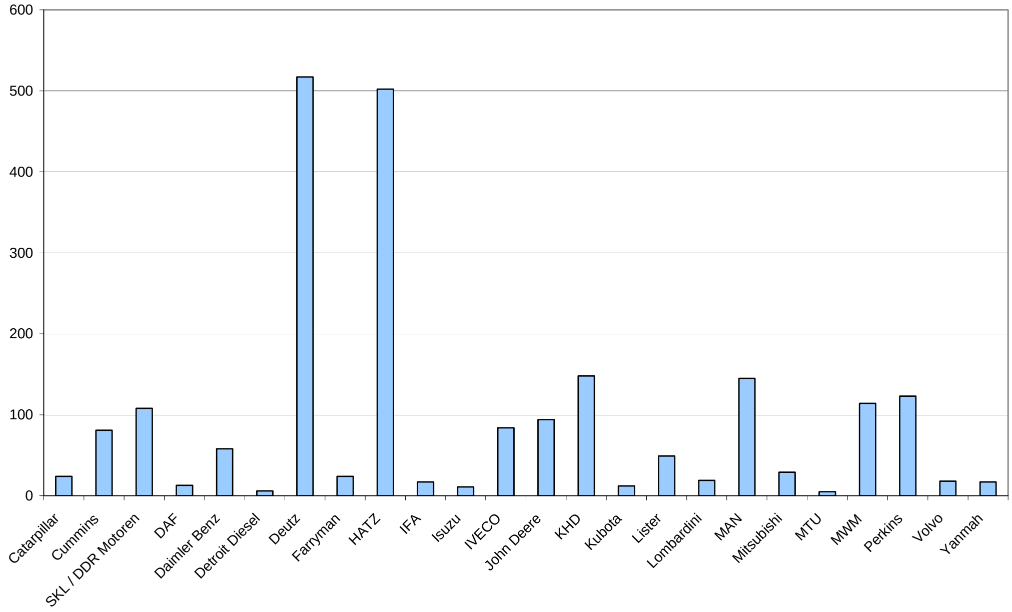



diagram 2.20: process pumps – diesel engines used in German inland water transport [1]

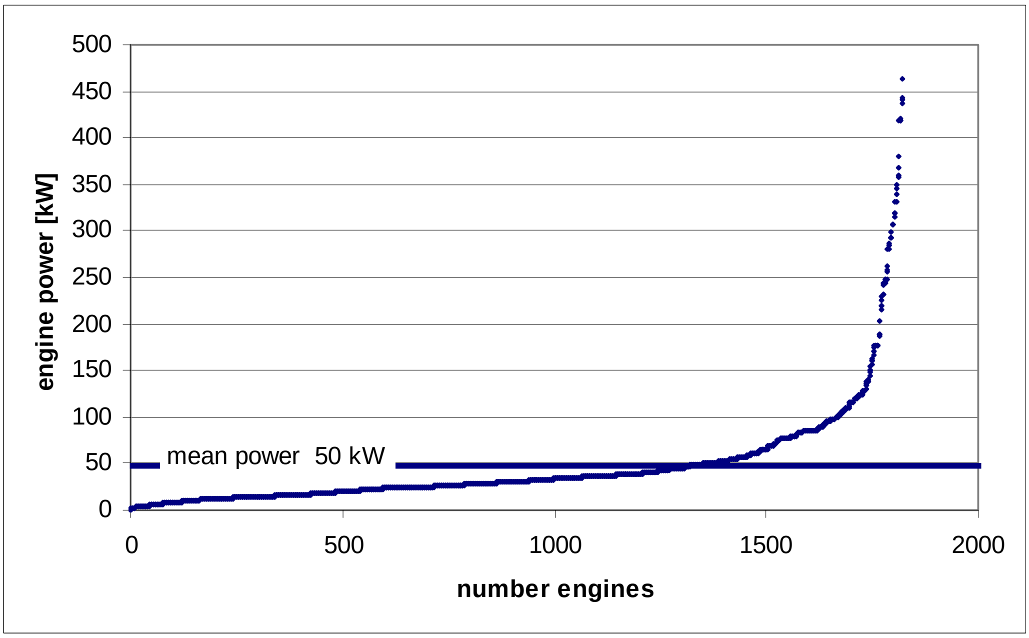



diagram 2.21: installed engine power of the process pumps – diesel engines [1]

Winch drives

Applied as stern und bow anchor winches, ca.100 engines with a medium power of ca. 8 kW are registered with ZSUK. A large number of these are engines made by engine manufacturers Farryman and Hatz.

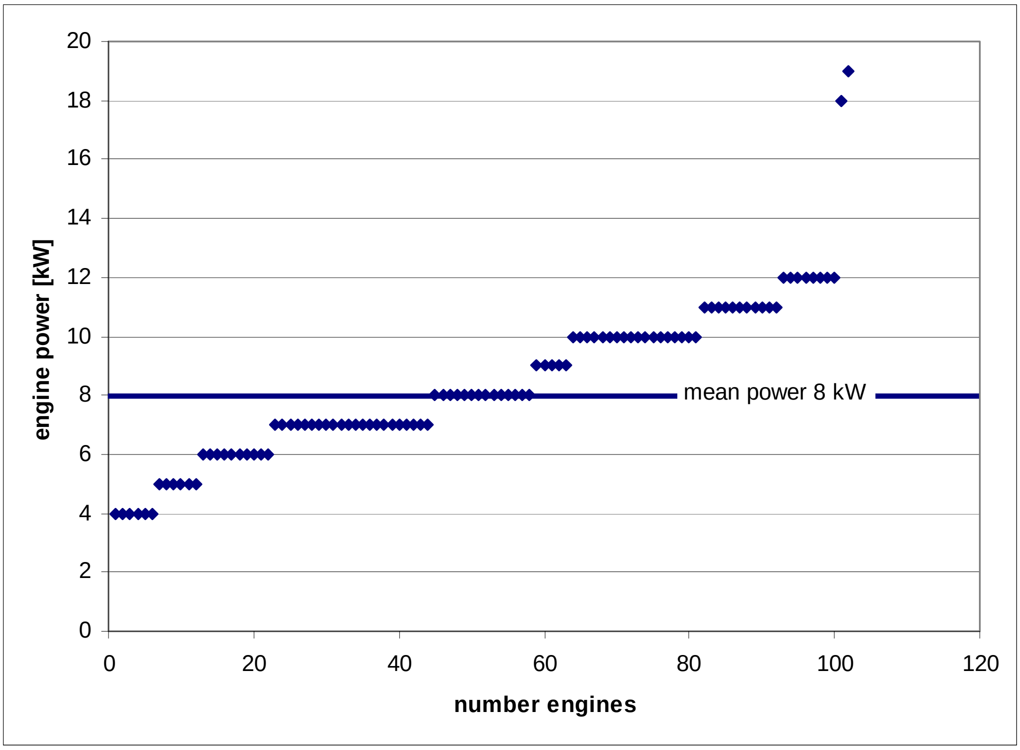



diagram 2.22: installed engine power of the winch drives – diesel engines [1]

## 2.3 Boiler plants

Boiler plants are applied on inland navigation vessels as boiler systems for meeting the sanitary heat demands, for heating living quarters and working rooms as well as for providing process heat. No records have been kept on the data of installed boilers on board inland navigation vessels. According to BDB can the data depicted in table 2.2 serve as the basis for engine power classes for the following discussion. Considering the durability of boiler plants, it can be assumed that plants above a duration period of more than 20 years are not likely to be in use any more. Chances are that the boilers are fired by means of a sprayer blowpipe.

table 2.2: engine power classes of boilers in use in the German inland water transport [2]

| | *power* |
|---|---|
| *loading heating* | 1000 to 3500 kW |
| *freight shipping* | 35 to 50 kW |
| *passenger shipping* | 1000 people 450 to 500 kW<br>600 people 250 kW<br>400 people 150 kW<br>250 people 46 kW |

# 3. Analysis of applicable low sulphur gasoil with addition of bio components (RME)

## 3.1 Low sulphur, sulphur free fuel oil

At present in German inland navigation marine gasoil, respectively heating oil and diesel oil are applied. As the ships usually bunker just one type of gasoil all the other combustors on board run on identical fuel. Apart from the main engines, these are auxiliary engines for bow thrusters, generators, winches and the like as well as boiler plants.

The quality of diesel fuel and heating oil has been regulated in Germany and has to meet specific standards which are shown in tables 3.1 and 3.2 .

According to BDB, it can be assumed that ca. 80 % of the German inland water transport crosses borders. Therefore, fuels for inland water transport can also be bunkered in the Netherlands (VOS – specification), Austria (ÖC 1109), Switzerland (SN 8181160-2) and in East European countries. While for diesel fuels single market standards with detailed specifications exist, gasoil and heating oil qualities are subject to national regulations and specifications. Solely the upper level of sulphur in marine fuels has to meet European Norm 1999 / 32 EG modified in European Directive 2005 / 33 EG.

Taking into consideration that marine fuel suppliers from the Netherlands offer gasoil for the main shipping area, the Rhine, on clearly more favourable conditions than German vendors, explains that ca. 80 % of the Rhine fleet bunker gasoil in the Netherlands according to an estimation by the BDB

Gasoil, respectively heating oil is applied mainly in stationary power plants or as fuels on board inland navigation vessels. In the Netherlands, stationary power plants are overwhelmingly run on natural gas, they don't have national standards for the quality of marine gas and heating oil but just guidelines after VOS - specification. These are close to German standards.

table 3.1 : properties diesel fuel according to DIN EN 590

| **properties** | | **requirements** min. | max. |
|---|---|---|---|
| cetane number | - | 51,0 | - |
| density at 15°C | kg/m³ | 820 | 845 |
| sulphur content | mg/kg | - | 50 |
| flashpoint | °C | > 55 | - |
| coke residue | % (m/m) | - | 0,30 |
| ash content | % (m/m) | - | 0,01 |
| water content | mg/kg | - | 200 |
| oxidation stability | g/m³ | - | 25 |
| lubricity | µm | - | 460 |
| viscosity 40 °C | mm²/s | 2,00 | 4,50 |

table 3.2: properties gas- respectively heating oil acc. to DIN 51603–1; 2003 – 09 [3]

| **properties** | | **requirements** min. | max. |
|---|---|---|---|
| density at 15 °C | kg/m³ | | 860 |
| heat value | MJ/kg | 42,6 | |
| flashpoint in closed crucible after Pensky-Martens | °C | > 55 | |
| cinematic viscosity at 20 °C | mm²/s | | 6,00 |
| coke residue after Conradson, (of 10 % distillation residue), given as mass fraction | % | | 0,3 |
| sulphur content for heating oil EL-1-standard | mg/kg | > 50 | – |
| given as mass fraction | % | > 0,0050 | 0,20 |
| sulphur content for heating oil EL-1-low sulphur | mg/kg | – | 50 |
| given as mass fraction | % | – | 0,0050 |
| water content, given as mass fraction | mg/kg | | 200 |
| overall soiling, given as mass fraction | mg/kg | | 24 |
| ashes, given as mass fraction | % | | 0,01 |

| properties | | requirements min. | max. |
|---|---|---|---|
| cetane number | - | 45 | |
| density at 15 °C | kg/m³ | | 860 |
| heat value | MJ/kg | | |
| flashpoint in closed crucible after Pensky-Martens | °C | > 60 | |
| cinematic viscosity at 20 °C | mm²/s | | 6,00 |
| coke residue after Conradson, (of 10 % distillation residue), given as mass fraction | % | | 0,3 |
| sulphur content for heating oil given as mass fraction | mg/kg | | 2000 |
| | % | | 0,20 |
| water content, given as mass fraction | mg/kg | | 200 |
| overall soiling, given as mass fraction | mg/kg | | 24 |
| ashes, given as mass fraction | % | | 0,01 |
| lubricity | µm | - | 460 |

table 3.3: properties gasoil, respectively heating oil acc. to VOS - specification

The specifications illustrate that diesel fuels as well as gasoil and heating oil containing varying levels of sulphur are on offer. The sulphur content of fuels has been restricted to a maximum value in all of the specifications. Hence it is absolutely possible that already at this stage fuels with significantly lower levels of sulphur than required are being applied.

Sulphur as such is an undesirable component in fuels. During the combustion process, the sulphur bound in the fuel is completely converted into $SO_2$. In addition, it supports particulate emission. If the dew point exceeds lower limits (D < 180°C) in the flue gas stream, sulphuric acid is formed in the water steam mixture, which causes wet corrosion of the exhaust conducting parts of the machine.

On the one hand, the application of low sulphur fuels leads to less $SO_2$-containing exhaust gas and particulates. This provides better conditions for after treatment of exhaust gas (catalysts and the like) and reduces strain on the engine components enclosing the combustion chamber or conveying exhaust gas.

On the other hand, a higher amount of polar bonds in a fuel with higher levels of sulphur support its lubricity, the elastohydro dynamic lubrication.. Lubricity in a fuel is influenced by:

- the number and arrangement of polar chains (foreign atoms),
- the content of di and tri aromatic hydrocarbons and
- the length of the paraffin chains. [4]

For the production of low sulphur fuels, an after treatment in form of hydrogenation of varied intensity, dependent on the quality of the crude diesel oil, is necessary to carry out in the refinery. During this process, a large number of polar bonds are lost, which results in the refining of a fuel possessing inadequate lubricity qualities. When defined lower limits are exceeded, the impaired lubricity of the fuel can be responsible for stronger wear, severe damage up to total breakdown of the engine components which were to be lubricated by the fuel. In order to secure lubricity, additives need to be added or blending with gasoil possessing higher lubricity properties is necessary,

Lubricity has an influence on the elastohydrodynamic lubrication of paired engine components, thus being essential for their functioning and equally for the wear- and construction component behaviour of fuel conducting parts, specifically in injection systems of engines and in the combustion system of boilers.

Lubricity is given in µm. The value is determined in a standardised test (HFRR-test) from the medium diameter of a wear affected area in the test set-up. In this experiment, a ball is moved back and forth at a frequency of 50 Hz and a downforce of 2 N over a distance of 1 mm for 75 minutes at constant temperature and humidity. This results in an oval wear area, which is measured in both expansions. The mean value is equal to the medium diameter and constitutes the parameter for the lubricity of the tested gasoil.

## 3.2 Realisation of the qualities of low sulphur and sulphur free fuels

The fuel properties included in the above specifications represent the permissible minimum and maximum values. Within these limits, the values can vary a great deal depending on the gasoil used. This is due to the quality of the crude oil that is processed and the refinery.

Table 3.4 shows the comparison of how the standards according to DIN EN 590 are met in diverse “sulphur free“ diesel fuels.

table 3.4 : analyses diesel fuels with sulphur contents < 10 ppm after [5] and [6]

| **properties** | | **DIN EN 590** | | **DF – 1** | **DF – 2** | **DF – 3** | **DF – 4** |
|---|---|---|---|---|---|---|---|
| | | **min.** | **max.** | [5] | [5] | [5 | [6] |
| cetane number | - | 51,0 | - | - | 52,3 | 56,0 | 54 |
| density at 15°C | kg/m³ | 820 | 845 | 836,3 | 823,9 | 826,8 | 833,8 |
| sulphur content | mg/kg | - | 50 | 9,5 | 8,0 | 8,3 | 3 |
| flashpoint | °C | > 55 | - | 67,0 | 62,0 | 72,0 | 84,0 |
| coke residue | % (m/m) | - | 0,30 | < 0,01 | - | - | < 0,01 |
| ashes content | % (m/m) | - | 0,01 | < 0,01 | - | - | < 0,005 |
| water content | mg/kg | - | 200 | 52 | 42 | 102 | 40 |
| oxidation stability | g/m³ | - | 25 | 1,24 | 1,43 | 1,44 | 3 |
| lubricity | µm | - | 460 | 327 | 314 | 323 | 374 |
| viscosity 40 °C | mm²/s | 2,00 | 4,50 | 2,58 | 2,02 | 2,60 | 2,712 |

The fuels DF-1, DF-2 und DF-3 were selected after [5] from the products of various refineries according to their respective oxidation stability parameters. The values for DF-4 were taken from [6].

To sum up, it can be stated that the lubricity of all diesel fuel samples, despite in parts distinctly lower levels of sulphur, is fully ensured by the manufacturers and lower limits were partly significantly exceeded. It is clearly recognisable that not only sulphur levels and lubricity, but almost all of the other parameters are subject to major variations within the limits set by the EU standard due to different crude oil qualities.

Concerning the provision of low sulphur and sulphur free gasoil for inland water transport, it can be assumed that the additives in use for ensuring the necessary lubricity do not differ from the additives used with the diesel fuel supply for road traffic.

## 3.3 Bio component fuels (RME)

As bio fuels in terms of BioKraftQuG (bio component fuels ratio regulations) are classified:

- fatty acid methyl ester (biodiesel), when they have been made by esterification of plants or animal oils or fats (animal fats only allowed up to the year 2012) and meet at least the requirements of DIN EN 14214,
- bioethanol with a minimum alcohol content of 99 percent by volume and when meeting the requirements of the drafted DIN EN 15376 and
- plant oil when aligned with DIN V 51605.

In DIN EN 590, setting the standards for diesel fuel, an addition of fatty acid methyl ester (FAME) up to a maximum content of 5 percent by volume is allowed for. According to BioKraftQuG and DIN EN 590, diesel fuel can be mixed with biodiesel. This does not require marking if 5 percent by volume are not exceeded. With higher percentages, however, marking is binding. The following remarks refer to biodiesel, in particular rape seed methyl ester. Table 3.5 illustrates the mandatory minimum requirements for biodiesel.

Apart from plant oil and biodiesel (bio component fuel of the first generation), synthetic bio component fuels, also known as bio component fuels of the second generation, such as BTL, Synfuel or Sunfuel®, are currently being developed. They are manufactured in a two-stage process by gassing biomass as the first step and synthesising it afterwards as the second step. The best known process for making synthetic bio component fuel is the Fischer-Tropsch-synthesis. By modifying certain parameters during the synthesising process and an after treatment preparation, the properties of the fuel can be adapted to the purpose. Hence they are also called tailor-made fuels. Contrary to the bio component fuels of the first generation, these oils can be applied in engines without any technical changes needed. It is presently thought that the BLT fuels will reach relevance for the market after 2010.

table 3.5: properties biodiesel acc. to DIN EN 14214

| **properties** | | **requirements** min. | max. |
|---|---|---|---|
| ester | % (m/m) | 96,5 | |
| density at 25°C | kg/m³ | 860 | 900 |
| viscosity bei 40°C | mm²/s | 3,5 | 5 |
| flashpoint | °C | above 120°C | |
| CFFP | °C | - | |
| sulphur residue | mg/kg | | 10 |
| coke residue (of 10% distillation residue) | % (m/m) | | 0,3 |
| cetane number | | 51 | |
| ash (sulphate ash) | % (m/m) | | 0,02 |
| water content | mg/kg | | 500 |
| overall soiling | mg/kg | | 24 |
| corrosion effect on copper (3h at 50°C) | corrosion degree | 1 | |
| oxydation stability, 110°C | hours | 6,0 | |
| acid number | Mg KOH/g | | 0,5 |
| iodine number | | | 120 |
| linolenic acid content | %(m/m) | | 12 |
| methanol content | %(m/m) | | 0,2 |
| monoglyceride | %(m/m) | | 0,8 |
| diglyceride | %(m/m) | | 0,2 |
| triglyceride | %(m/m) | | 0,2 |
| free glycerine | %(m/m) | | 0,02 |
| overall glycerine | %(m/m) | | 0,25 |
| alkali content (Na+K) | mg/kg | | 5 |
| phosphorus content | mg/kg | | 10 |

The importance of selected properties and the effect when minimum requirements are not observed can be summarised after [7, 8, 9, 10, 11 ] as follows:

- A number of the properties of biodiesel fuel are the result of the manufacturing process and do generally not arise from the properties of the plant oil employed. Therefore, characteristics of insufficient transesterification (e.g. methanol content, triglyceride, monoglyceride, diglyceride as well as free glycerine and total glycerine) can lead to wear in the fuel injection system respectively combustor system and to coking in the combustion chamber. An increase of the methanol content makes the flashpoint decline.

- An increased alkali content causes saponification and deposition of soap. It leads to machine halt due to filter off-set and can be the reason for increased ash content.
- Special attention needs to be paid to fuel stability and strict compliance with the limit value of phosphorus content. Phosphorus is contained in plants in form of phosphorous lipids. The hydrogenation property of phosphorus causes phosphorus-rich oils to form deposits under the influence of variations in temperature and condensation water which is related to it. These deposits can form a rich culture medium for microbial decomposition. Apart from its ability to hydrogenate and decrease oxidation stability, phosphorus lowers the combustion temperature. Phosphorus can be traced in the deposits of the engines. Moreover, oxidation catalysts are highly sensitive to phosphorus compounds. Violation of the limit value, however, doesn't practically occur any more [11].
- The quality of biodiesel can be drastically impaired under the influence of oxygen due to oxidation processes. This is supported by light, heat and catalytically functioning heavy metals. This leads to the formation of compounds of low solubility which results in the clogging of fuel filters. Furthermore, interaction with the lubrication oil may occur. The ageing status is defined by the oxidation stability. Plant oils with a larger content of unsaturated fatty acids (e.g. sunflower oil, rape seed oil, soy bean oil) possess a lesser oxidation stability than oils with a larger portion of saturated plant oils (e.g. palm oil, coconut oil). Biodiesel based on raw materials which are rich in saturated fatty acids have, however, poorer cold flow properties. Hence filter clogging has been ascribed to the use of palm oil methyl ester blends [8]. Essential properties of biodiesel consequently depend on the choice of raw material. In order to improve oxidation stability and to ensure compliance with required cold flow property specifications (in particular winter diesel), appropriate additives are used. They majority of the additives, however, has only been tested after [8] for application with RME.
- The neutralisation value, respectively the acid number, is a measure for the number of free fatty acids. It is heavily dependent on the refining degree and ageing. Water in oil as well as micro organisms and enzymes can cause a hydrolytic decomposition of the triglycerides and raise the neutralisation value. Acid compounds can give way to corrosion, wear and formation of residues in the engine and may interact with lubrication oil components.

- For the use of biodiesel, you have to take its qualities as a solvent into account. This is essential for both the storage of the fuel (tank, tank coating, tank equipment) and engine operation (seals, fuel hoses, membranes). Adequate RME resistant materials and coating (e.g. made of fluoric rubber) need to be applied, respectively affected machine components have to be replaced regularly (e.g. annually) as recommended by the manufacturer.

Other properties of biodiesel can be rated as favourable in comparison with diesel fuel. Bio diesel is by its nature almost sulphur free, so $SO_2$- emissions and discharge of particles bound to sulphates are relatively small. Despite of this, biodiesel possesses good self-lubricity qualities. This is expressed in a HFRR – value of ca. 200 µm. In contrast, highly desulphurized mineral oil diesel (without additive) has a HFRR- value of 500 µm and higher. Equally, the naturally high cetane number can be regarded as positive. It ranges from 56 to 58.

### 3.4 Blending bio component fuels with diesel fuel

Table 3.6 below shows exemplarily data on how blending diesel fuel DF-1 with 5 percent by volume and 20 percent by volume biodiesel affects the properties of low sulphur fuels after [5]. Furthermore, parameters when adding 1 percent by volume RME after [4] have been included as another example.

table 3.6: test parameters - blending bio component diesel with low sulphur fuel [5, 4]

| **properties** | | **DIN EN 590 min.** | **max.** | **DF – 1** [5] | **B5-Blend 5 % - RME** [5] | **B20 Blend 20 % - RME** [5] | **DF 1 % - RME** [4] |
|---|---|---|---|---|---|---|---|
| cetane number | - | 51,0 | - | - | 52,6-55,8 | 52,3-55,6 | kA. |
| density at 15°C | kg/m³ | 820 | 845 | 836,3 | 826,8-838,5 | 837,2-845,3 | 830 |
| sulphur content | mg/kg | - | 50 | 9,5 | 8-9 | 7-8 | 5,0 |
| flashpoint | °C | > 55 | - | 67,0 | 59,5- 67,5 | 61,5- 70,5 | 90 |
| coke residue | % (m/m) | - | 0,30 | < 0,01 | | | |
| ash content | % (m/m) | - | 0,01 | < 0,01 | | | |
| water content | mg/kg | - | 200 | 52 | | | |
| oxidation stability | h | | | 1,24 | 18,2 – 40,6 | 14,0 – 19,8 | 2,1 (IP 306) |
| lubricity | µm | - | 460 | 327 | 225-251 | 203-243 | 273 |
| viscosity 40 °C | mm²/s | 2,00 | 4,50 | 2,58 | 2,1 – 2,667 | 2,364 – 2,858 | 3,38 |
| Neutralisation number | mg KOH/g | | | | 0,01-0,08 | 0,03-0,09 | 0,02 |
| overall soiling | mg/kg | | | | 2-5 | 2-3 | 7,5 |
| FAME-content | Vol % | | | | 4,7 | 18,3-19 | |
| cloud point | °C | | | | -1- -13 | -25 - 0 | kA. |
| CFPP | °C | | | | -2 - - 13 | -2 - - 25 | kA. |

All the fuel mixtures tested meet the DIN EN 590 standards after [5]. Oxidation stability, which differs greatly in the various types of blend, is currently not standardised. Neither are further properties essential for application such as, for example, solvent ability not taken into account.

The findings presented in [4] confirm this statement up to a portion of 5 percent by volume RME. With the biodiesel batches examined, however, a very low oxidation stability was found, which made compliance with the limit value impossible.

The findings concerning influences on the properties of diesel fuel blended with RME can be summed up as follows:

- Density, viscosity, CCR - value and flashpoint rise with growing RME portion. .
- The boiling behaviour is moved to higher temperatures.
- The sulphur content decreases.
- The Cetane number/cetane number index remain principally unaffected with 1 percent by volume [4]. After values in [22], a rise of the cetane number with B5 and B20 is possible.
- The lubricity (HFFR test) is significantly affected. In [4], with portions from 1 % up the HFFR value of 460 is exceeded, and a complete lubrication film is formed without application of additives. It is thought that an elstohydrodynamic lubrication film develops from 1 vol-% portion up. With 0,75 vol-% a change-over area is showing. The RME-portion can replace the polar bonds partly lost in the manufacturing process of sulphur free diesel fuels.
- Biodiesel does not contain any poly aromatic hydrocarbons, so by blending their total amount decreases [12].
- The oxidation stability improves compared to pure FAME-fuel (significant increase of the induction time). A comparison of the DF samples tested shows, however, an irregular pattern.. After [4], the oxidation stability decreases with rising biodiesel portion, after [5], even an increase of the induction time as compared to pure DF has been found for one fuel. The fuels with 20 vol-% biodiesel portion (B20) show a lower oxidation stability in contrast to 5 vol-% biodiesel portion. They lie, however, clearly above the biodiesel samples examined. The induction time of pure diesel has little effect on the induction times of the blends with 20 vol-% portions. Batches with longer induction times tend after [5] to show lesser sludge- and overall acid formation. According to the findings, the oxidation stability is difficult to predict even though the induction time of the DF and RME used are known.

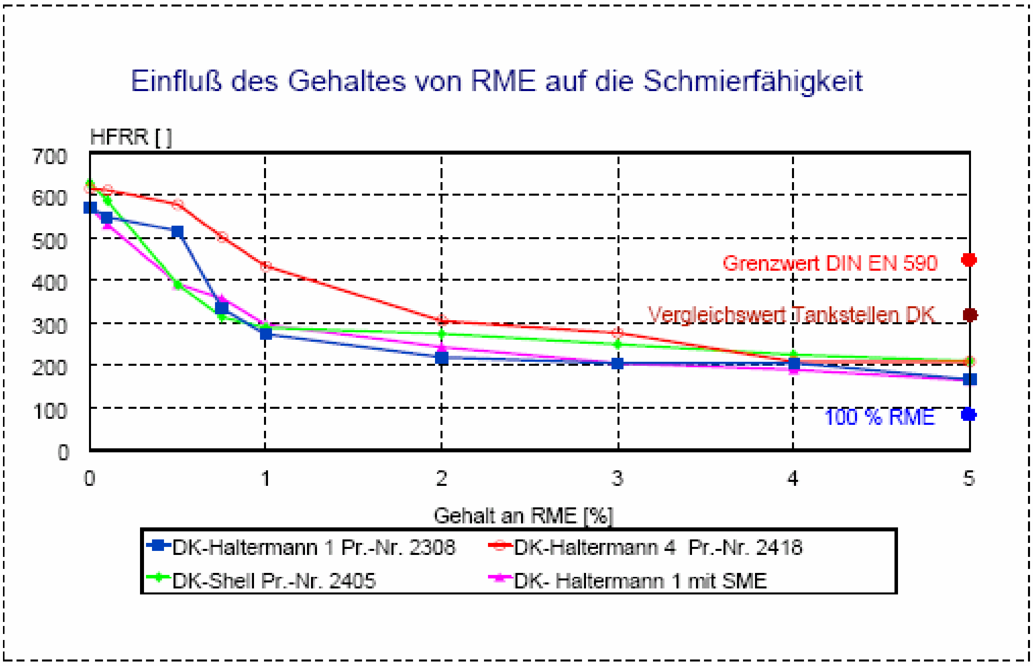



diagram 3.1: influence of RME portion on lubricity [4]

Studies on the storage of various bio component fuels after [13] illustrate that the peroxide number, that constitutes a measure for their oxidative deterioration, does not change significantly, respectively not at all when diesel fuel with an RME- portion of 10 vol-% is stored for 96 weeks, neither when stored in a metal tank (storing temperature 5°C), in a PE-metal tank and PE-tank indoors nor in a metal tank outdoors (shadeless).

Solely under the influence of light (PE tank outdoors, shadeless), the peroxide number rises to a certain extent. This means that stable storage of fuel blends below 10 vol-% can be reached if all given parameters are correctly implemented and the conditions are met. Whether the same arrangements recommended with 100 % RME need to be made for the existing tanks and tank applications, remains subject to further examination (tank coating, removal of older deposits, etc.).

Within the scope of the DGMK study [5], interaction between FAME- and diesel additives at 5 vol-%, respectively 20 vol-% RME or old edible oil methyl ester was examined. The following parameters were applied:

| | | |
|---|---|---|
| DF | flow conditioner (MDFI) | 500 ppm |
| | wax anti settling additive (WASA): | 250 ppm |
| FAME | cooling additive (MEFI): | 2500 ppm |
| | oxidation stabiliser (BHT) | 100 ppm (B5),<br>500 ppm (B20) |

For the NO-Harm tests (emulsion behaviour, minimum blending temperature, corrosion behaviour, duration stability, foaming behaviour) the following findings can be summarised:

B5 blends:

- The blending of RME and DF didn't have any negative effects.

B20 blends:

- Foaming is negatively affected by blending with 20 vol-% FAME. The tendency towards emulsion formation increases. Other effects of FAME and FAME- flow conditioners have not been found.
- Modification of the oxidation stabiliser can change the emulsion behaviour. Negative influences on duration stability, minimum blending temperature and foaming behaviour have not been found.

The following general statements can be made on the application of fuel blends:

- B5-fuels which meet the DIN EN 590 and DIN EN 14214 standards have been approved for by engine manufacturers engine test beds [4, 5] have shown that these blends do neither increase the risk of layering nor the wear risk.
- Higher portions of biodiesel in the blend affect its properties both positively (lubricity) and negatively (fuel stability, solution ability) and must therefore be taken into account when the blend is applied. The engine needs to be adapted / refitted if necessary. An increase of the biodiesel portion from 5 to 10 % causes NBR-elastomeres to lose much of their tear- and tensile strength. The maceration behaviour is significantly increased [12, 14].
- In agreement with the appropriate conditions (cool, dark) can RME and blends be stored over a longer period of time (maximum 2 years) without undergoing any major changes. [13].
- Which grade of blending requires the same preparations of tanks and tank equipment as common with pure biodiesel needs to be examined in further studies.

## 4. Evaluation of fuel compatibility in energy plants applied in inland water transport

It is expected that unified regulations on the observation of limit values and fuel standards to be met in inland navigation are set for the shipping areas. A change-over to a new gasoil quality requires to make arrangements for meeting the specific demands on storage, preparation and application of the fuels. Measures for the adaptation of existing system components, modification of the engine management and selection of suitable lubricants and operation means may become necessary. Hence a permanent changing between gasoil qualities is not sensible and therefore excluded from the further discussion of the issue.

In inland water transport, exclusively medium fast running and fast running diesel engines are applied as main engines of the vessels, as bow thrusters and equally as driving engines of generators, pumps and winches both with older and more recent engines. The energy power class for main engines ranges from 150 kW to 1 300 kW, for driving engines of bow thrusters and loading pumps from 100 to 300 kW. The capacities of generator- and winches driving engines is significantly smaller, lying between 10 and 50 kW.

Engines of the energy power class 150 to 1 300 kW and bigger are equipped by a few manufacturers with adaptors to the respective engine application and are also serviced by them. Engines with smaller capacities are built by a great number of manufacturers, who make a vast variety of standardised engines to meet the most varied needs.

The following assessment of fuel compatibility focuses mainly on main engines and the driving engines of bow thrusters. For this purpose, the database on installed main engines in inland navigation vessels, prepared in the study “Erarbeitung von Verfahren zur Ermittlung der Luftschadstoffemissionen von in Betrieb befindlichen Binnenschiffen“ and the ZSUK database of 2007, containing details on the complete fleet of inland navigation vessels are exploited.

The masses of data on the registered auxiliary engines for generator and winch drives in inland water transport made available by ZSUK do not allow for a detailed analysis of fuel compatibility. Fundamental statements, however, can be made.

A reliable database on boiler plants aboard vessels does not exist. For further discussion the energy demand of boiler plants has been deduced from essential parameters of the ships. [15].

## 4.1 Low sulphur, sulphur free fuels

### 4.1.1 engine plants

### 4.1.2 fuel system

fuel injection system

A reduction of the sulphur content to 50 ppm, respectively 10 ppm has a major influence on the lubricity of the gasoil. The lubricity of the gasoil is essential for the lubrication of moving components in the fuel injection system and the injection nozzle of the diesel engine. Depending on the construction and technical parameters of the fuel injection unit applied, specific demands on the gasoil that is to be used must be met.

The engines applied in inland navigation as main engines and driving engines of bow thrusters belong to an energy power class, in which unit- or in-line fuel injection pumps, with more recent engines also common-rail systems, are used. Contrary to distributor pumps, which are mainly installed with diesel engines of lower power, the driving gear unit of the unit- or in-line pumps is lubricated separately or coupled with the circulation lubrication system of the engine. The lubricity properties of the gasoil are relevant only for fuel-conveying engine components (injection pump plunger and cylinder). This is different with distributor injection pumps and with modern common-rail systems. All the moving engine components are lubricated by the gasoil. Modern diesel engines of lower power can also be equipped with pump-nozzle systems, in which high-alloyed engine oils function as lubricators for most of the engine components.

Demands on the tribological system of the fuel-carrying engine components (plunger and cylinder) and the injection nozzle are low because of high fitting accuracy und just minimal shearing forces associated with them, which could otherwise destroy the lubrication film. The wear behaviour is mainly affected by impurities of the fuel [4].

The ball bearing units, cogwheels, rams and rollers of the driving gear unit of distributor injection pumps are lubricated in form of hydrodynamic lubrication, which makes special demands on the lubricity properties of the gasoil. These engine components are subject to heavy loads with enormous areal pressing and pressures between moving bodies. Mixed friction and with it increased wear of the body surfaces can only be prevented when a hydrodynamic lubrication film is formed.
For the assessment of the lubricity of a gasoil, the mineral oil and engine industry have developed a testing method, the HFRR test described in chapter 3.1.
With reference to what was said about properties of low sulphur, respectively sulphur free diesel- and other gasoil fuels in chapter 3.1, the lubricity of fuels is achieved by adding additives. Appropriate additives are available and are added to the standard fuels by the mineral oil industry. They ensure sufficient lubricity, prevent the formation of deposits in the fuel system and have a positive influence on the combustion process. Likewise, the blending with bio component fuels such as RME increases the lubricity of the fuels. A bio component portion above 1 % RME is sufficient to reach the required lubricity of 460 µm without addition of any additives [4].
When a fuel lubricity value of 460 µm is secured, a safe operation of the engine with modified fuel injection pumps and –nozzles is principally given. This has been confirmed by the manufacturers of fuel injection pumps BOSCH and L'Orange. As for the wear behaviour of injection pump plungers and fuel injector needles of older engines, which are partly not coated, no valid data are available.

*Recommendation*

Due to the changes in construction parameters of the fuel injection pumps and changed material properties over the period under discussion, the periodical intervals of corrective maintenance and servicing of the engines should be used to check on the wear behaviour of the engine components. Heating or mixed friction, respectively solid parts friction of tribological pairing is not to be expected. If necessary, pump elements and injection nozzles should be replaced by coated components. The maintenance and servicing measures carried out by service and authorised repair shops do not cause any substantial additional costs.

<u>Oil seals</u>

Impairment of sealing materials through the application of low sulphur, respectively sulphur free gasoils, in particular in fuel injection pumps, is not to be expected as the European engine oil industry set limits to the portion of aromatic hydrocarbons in accordance with defined standards, which minimises the risk of damage on seals. Already since the ‘50s, elastomere sealing materials such as fluorine-rubber (Viton) and nitrile-butadiene rubber (NBR) have been in use as sealing material.

*recommendation*

The application of low sulphur, respectively sulphur free gasoil fuels has not brought about any specific demands on sealing properties of the materials nor on particular maintenance and repair measures..

<u>Filter</u>

Damages or negative effects on fuel filters through the application of low sulphur, respectively sulphur free fuel oils can be excluded.

*Recommendation*

The application of low sulphur, respectively sulphur free gasoil fuels has not brought about any specific demands neither on the qualities of filters to be applied nor on maintenance and repair measures.

#### 4.1.1.2 Combustion process

The application of low sulphur, respectively sulphur free gasoil fuels does not exert any influence on major fuel parameters relevant for the combustion in diesel engines. Flashpoint, boiling process (table 3.4) and combustion duration can vary. This affects the ignition point and the combustion process as well as the combustion duration. This can be compensated with the help of engine specific adjustment of parameters if necessary.

At present, expert panels of CIMAG examine whether it is necessary to set new national and international standards for characteristic data of gasoil fuels due to changed parameters of ignition properties of the fuels [16].

*Recommendation*

In case of noticeably changed ignition properties with consequences for the combustion process, engine specific parameters have to be adjusted in order to achieve an optimal combustion. The engine specific adjustments carried out by service- and authorised repair shops within periodical maintenance and servicing measures do not cause any major additional costs.

### 4.1.1.3 Exhaust gas emission

The application of low sulphur, respectively sulphur free gasoil fuels has relieved the strain on the environment due to reduced exhaust gas emissions.

Large portions of sulphur in gasoil fuels cause high $SO_2$ – emissions in the exhaust gas which have a heavily damaging impact on the environment. There exists an almost linear interlinkage..

$$SO_2 = (21{,}9 \text{ x } S) - 2{,}1 \quad \text{kg / fuel}$$

Therefore, great efforts are being made nationally and internationally to reduce the sulphur portion in gasoil fuels. That applies both for road traffic (trucks, cars) and increasingly for inland and deep sea navigation.

On top of that, the sulphur content of a fuel has an influence on the emission of particulates (ca. 10 % - 20 % reduction). That applies both for quantity and structure of the particles..

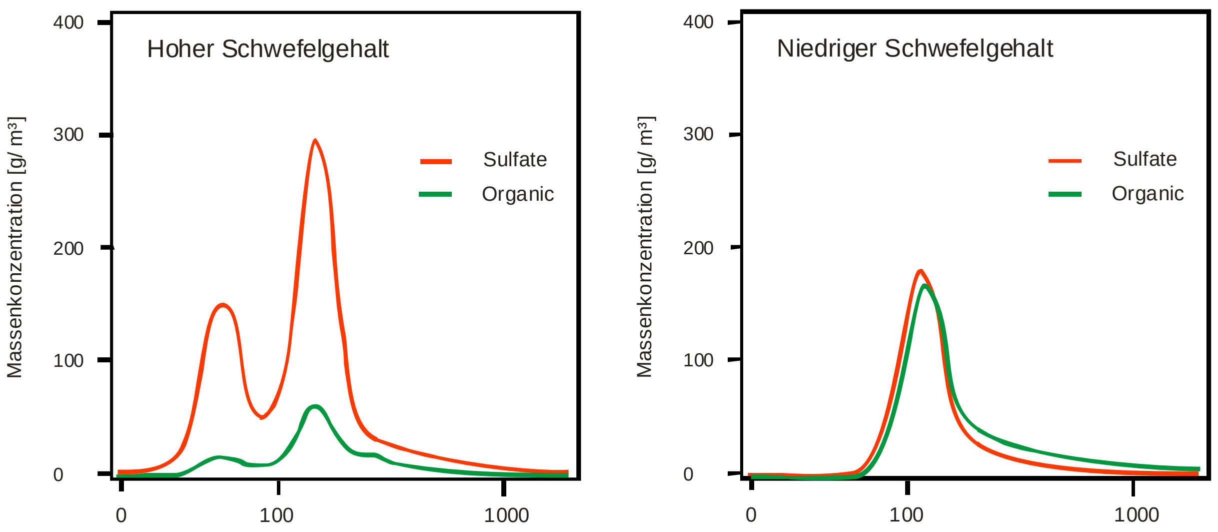



diagram 4.1: particle size distribution separated acc. to chemical composition after [17]

The composition of the particles depends greatly on the sulphur portion, for example.

| | | |
|---|---|---|
| sulphur content 3 % : | sulphate / metal oxides | – 60 % |
| | soot | – 25 % |
| | CH | – 10 % |
| | $H_2O$ | – 5 % |
| sulphur content 0,1 % | sulphate / metal oxides | – 10 % |
| | soot | – 45 % |
| | CH | – 40 % |
| | $H_2O$ | – 5 % |

*Recommendation*

The application of low sulphur, respectively sulphur free gasoil fuels has an exclusively positive effect on the emission behaviour of engines. Therefore, no specific demands on engine operation or periodical maintenance and servicing need to be met.

#### 4.1.1.4 Combustion chamber enclosing construction components

It is assumed that the application of low sulphur, respectively sulphur free fuels does not have any relevant consequences for the behaviour of the construction components enclosing the combustion chamber if they have been adjusted accordingly. The thermal impact on components caused by deposits and soot particles as well as wet corrosion is reduced.

It needs to be considered, however, that the changed combustion process of low sulphur -, respectively sulphur free fuels may result in the formation of spacious high-molecular, organic residues in the grooves of the cylinder liner, which greatly reduces its oil containing power. Under high thermal and mechanical loads this causes so-called lacquering of the liner surface. The process of lacquering on the liner surfaces may also be promoted by the application of engine oils with high TBN (high base number) in the combustion process of low sulphur, respectively sulphur free gasoil fuels. .

Generally can be said that the effective pressure ($p_e$) and likewise the mean speed of the piston ($c_m$) and with them the thermal and mechanical loads on the components enclosing the combustion chamber have drastically increased in the course of the last 50 years (diagram 4.2). The older engines used in inland navigation are exposed to significantly lower strain [1]. The tendency to lacquering under the influence of high temperatures is clearly lower with older engines than with the newer ones for this reason. By modification and optimisation of the combustion process, the lacquering of the contact surface of the cylinder liner be prevented.

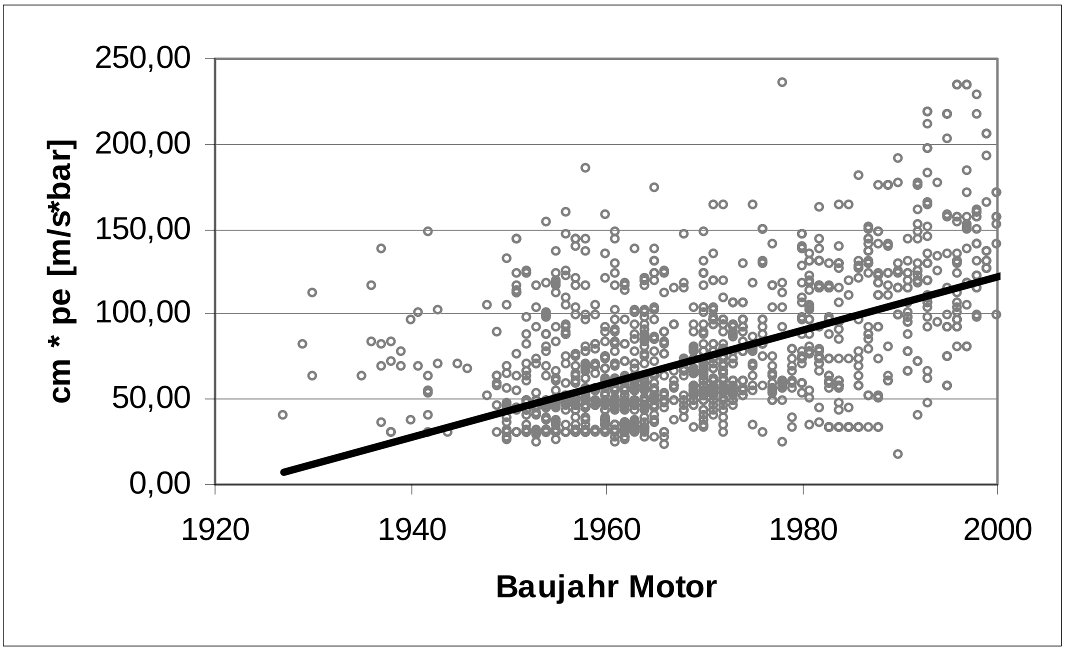



diagram 4.2: development mean piston speed * effective pressure ($c_m * p_e$)
– for main engines in German inland water transport [1]

The tendency towards lacquering through circulation oils of high TBN is answered by meaningful adjustment between the gasoil used and the engine lubrication oil. For this purpose, mineral oil manufacturers offer special lubrication products such as, for example, Mobilgard Delvac 1600 for medium fast running diesel engines with a fuel sulphur content of 0,3 % to 1,5 % (ExxonMobil).
The lubrication of the inlet and outlet valves on the valve seat area is achieved by the lubricity qualities of the gasoil. The lubrication between valve guide and spindle is ensured by the circulation oil of the engine..

*Recommendation*

Alongside with maintenance and servicing measures periodically carried out, the behaviour of construction components and wear behaviour of pistons, piston rings and cylinder liner should be regularly inspected and recorded. In case of growing wear- or soiling- and lacquering marks, shorter servicing intervals, respectively a renewed adjustment of gasoil and lubrication quality are recommended. By optimising the combustion process, a possible lacquering of the contact surface of the cylinder liner can be prevented. The choice of high quality materials for inlet and outlet valves and the valve seats can prevent excessive wear of these components. The above measures can easily be carried out by service and authorised repair shops without causing substantial extra costs.

#### 4.1.1.5 Exhaust gas system

The combustion products are released via the exhaust gas system. For further environmental benefits particle filters or catalysts can be included in the exhaust gas system. The use of low sulphur, respectively sulphur free gasoil reduces the danger of exceeding the lower limit of the dew point in the exhaust gas system. An excess of the dew point causes the formation of sulphuric acid, which is the reason for increased corrosion in the exhaust gas system

Particle emission reduces when sulphur free gasoils are used by 10 % - 20 % [18, 19]. This applies particularly to the sulphate particles. As the installed particle filters suffer damage from the precipitation of sulphates, the use of the low sulphur, respectively sulphur free gasoils is advantageous and reduces the operating costs.

For after treatment of the exhaust gas, catalysts which have been "contaminated" with sulphur are applied. The application of sulphur free gasoil results in longer engine durability and thus reduces overall costs.

*Recommendation*

The application of low sulphur, respectively sulphur free gasoils has exclusively positive effects on the behaviour of the construction components of the exhaust gas system. Therefore, no specific demands on the engine operation or the periodical servicing and maintenance measures need to be observed. .

#### 4.1.1.6 Lubrication oil system

The application of low sulphur, respectively sulphur free gasoils requires the use of especially modified, gasoil compatible lubrication oils. These lubricants are supplied by the manufacturers. By adding appropriate additives, the lubrication properties necessary for operation with low sulphur, respectively sulphur free gasoils can be achieved. Data on the composition and impact on the environment of lubrication oils are not available.

*Recommendation*

Changeover to fuel qualities of low sulphur, respectively sulphur free gasoils makes the adaptation to the lubricant qualities necessary. This should be done in close coordination with the manufacturers of engine– and mineral oils and the service- or authorised repair shop.

### 4.1.2 Boiler plants

Since July 2005 all sorts of oil-burning heat generators including combustion unit plants have been approved of for the use of low sulphur heating oils (max. 50 mg/kg). This low sulphur heating oil is in particular suitable for fuel value units and has the following advantages:

- almost residue-free combustion, lesser deposits and better heat transmission and higher efficiency
- reduction of the coking of the firing nozzle for
  - low sulphur heating oil (50 ppm) – 0,03 %
  - sulphur free heating oil (10 ppm) – 0,01 % [20]
- lesser threat of low temperature corrosion and subsequently lesser residues
- sulphur content < 100 ppm – no obligatory neutralisation.

For filters and seals apply the above statements for combustion engines. A deterioration of lubricity properties is compensated by the application of lubricity – additives (no ash forming components).

According to studies of IWO - Institut für wirtschaftliche Ölheizung [21], with the use of low sulphur heating oil may occur so-called metal dusting in the fire tube with iron- and nickel based materials. In extremely rare cases this may lead to severe damaging, it has been found mainly with blue flame burners with fire tube stabilisation and low - $NO_x$ burners with orifice plate stabilisation and flame peak attachment. Therefore some manufacturers of low sulphur heating oil only approve of ceramic fire tubes.

*Recommendations*

Problems for the operation of boiler plants with low sulphur, respectively sulphur free fuels are not to be expected. The fire tube of blue flame burners and low - $NO_x$ – burners has to be checked for metal dusting during the periodical maintenance and servicing measures. The minimal disturbances due to the metal dusting effect have to be answered by application of ceramic materials. These measures can by taken by authorised service stations or repair shops in the event of damage.

## 4.2 Blending bio component fuels (RME) with diesel fuel

For the evaluation of fuel compatibility of the energy systems related to mixing bio component fuels and diesel fuels, in particular blends with a biodiesel portion of >5%, there is a need for further studies as explained in the following paragraph. For this reason, experiences and recommendations available on the application of 100% biodiesel were exploited when necessary. As long as there no such recent experiences on the effect of the blending with bio component fuels have been recorded, the above mentioned should be taken into consideration.

### 4.2.1 Engine plants

#### 4.2.1.1 fuel system

<u>fuel injection system</u>

Contrary to standard diesel fuel, RME is of low heating value. Due to this, fuel consumption is likely to increase, dependent on the portion of biodiesel it contains. For 100% RME an additional consumption of 5 vol-% to 10 vol-% has been reported [7, 13, 22, 23]. An addition of 5 vol-% means a theoretical additional consumption of 0,5 %. Tests on the application of fuel blends, however, show that this value is partly too small for measuring [13]. There is no need to adapt the dimension of the fuel system.

For mechanically controlled injection systems, engine manufacturers [24, 25] have declared the application of standard diesel fuel with 5 vol-% biodiesel (DIN EN 590, biodiesel portion: DIN EN 14214) as non-hazardous.

The good self-lubricity quality of biodiesel has a positive effect so that the required HFFR value of 460 can be reached with a biodiesel portion of at least 1 vol-% without any other additives [4]. It has been recommended by engine manufacturers [24] to check on the components of the fuel injection systems more closely within the regular maintenance intervals, to recognise deviations from formerly common wear marks and soiling ratios.

First examinations have found no increased risk of layering and soiling with the use of blends of up to 5 vol-% [4, 5] as compared to the use of pure mineral oil based diesel fuel.

*Recommendation*

Up to a biodiesel portion of 5 vol-% the application of standard diesel fuel is rated non-hazardous. The instructions of the engine manufacturers have to be followed. The components of the injection systems have to be scrutinised within regular inspection intervals. On the effects of larger biodiesel portions in the fuel further studies have to be carried out.

<u>Seals</u>

For the use of biodiesel its properties as a solvent need to be taken into account. This applies on the one hand, for the storage (tank, tank coatings, tank equipment) and on the other hand, engine operation (seals, fuel hoses, membranes). For the use of 100 vol% biodiesel, appropriate RME- resistant materials and coatings (e.g. out of fluoric rubber) need to be applied, respectively affected elements need to be regularly replaced (e.g. annually) in accordance with the instructions of the manufacturer [7].

First experiences with elastomere compatibility show that an increase of the biodiesel portion from 5 vol-% to 10 vol-% leads to a substantial loss of the tear and tensil strength of NBR elastomeres, and their maceration behaviour increases noticeably. Higher temperatures promote the effect with increasing biodiesel portions [12, 26, 27]. Because of their history, older engine installations may have an increased damage risk, e.g. due to elutriation of plasticisers. With a portion of ≥ 5 vol-% biodiesel, the deterioration of the tear strength becomes obvious. Other parameters are similar to diesel fuel.

*Recommendation*

Generally, it can be stated that an addition of biodiesel up to 5 vol-% does not necessarily require an exchange of sealing materials as a precondition for its application, but that their performance under the influence of biodiesel ratios needs to be checked.

When reactions of the sealing materials become noticeable or with the use of higher portions of biodiesel, RME- resistant materials and coatings (e.g. fluoric rubber) need to be applied, respectively need to be replaced regularly according to manufacturer instructions. The applicability of , for example, fuel hoses for biodiesel has been rated by their manufacturers.

Filters

The solvent qualities of biodiesel can cause the dissolution of diesel fuel residues and lead to clogging of the filters. For this reason, manufacturers prescribe [24] shorter replacement intervals for the filters (with every change of crankcase oil when pure biodiesel is applied and likewise the replacement of fuel filters and engine oil filters 25 hours after changeover to the new blended fuel quality.

Due to increased "oxidation stress" at storing (high temperatures, frequent exposure to atmospheric oxygen, UV-radiation, contact with nonferrous heavy metals), there is the threat of polymerisation, which causes an increase of fuel density that may also result in the clogging of filters.

As there are no secured data on the solution behaviour of diesel fuel blended with biodiesel available, the filter should be scrutinised after changeover (first application) to the blended fuel as prescribed for the application of pure biodiesel. When with engines in stock the biodiesel ratio dissolves old residues, the duration period of the filters is likely to reduce.

*Recommendation*

With the first application of fuel blends containing a biodiesel portion of up to 5 vol%, the filters have to be checked after changeover. If diesel fuel residues are dissolved due to the solvent qualities of the biodiesel portion, reduced duration periode of the filter are to be expected.

The use of higher portions in engines, solely to be approved for by the manufacturers, is likely to bring about a stronger effect. The instructions for approved for engines have to be cleared up in close contact with the manufacturer and followed.

### 4.2.1.2 Combustion process

Diesel engines are designed to run on mineral diesel fuel. The blending with biodiesel should not bring about any combustion process related disadvantages. Engine manufacturers have declared the addition of biodiesel of max. 5vol% after DIN EN 590 to standard diesel fuel safe [12].

*Recommendation*

No combustion process related disadvantages due to the application of 5 vol-% biodiesel have been found.

#### 4.2.1.3 Exhaust gas emissions

With the application of biodiesel with the exception of $NO_x$-emissions, improved values have been found, for example, of carbon dioxide, sulphuric emissions and hydrocarbon-, soot- and PAK-emissions as compared to mineral diesel fuel. Examinations on graded addition of RME portions to diesel fuel show an almost straight proportional correlation between the changes of emissions and the change of the blending ratio Any over proportional effects have not been found [22, 28]. Thus, for example, the emissions of hydrocarbon and the soot number decrease, whereas nitrogen oxide emissions increase with a growing portion of RME. As for the reduction of harmful substances, there are means to adapt the engine to the physical differences of biodiesel by variation of the injection mass, the injection point and the injection process [23, 28].

*Recommendation*

The application of biodiesel affects the emission behaviour in a positive way with the exception of $NO_x$-emissions. There are no special demands on the operation of engines. If necessary, a modification of parameters of the injection process as mentioned above can be carried out to reduce harmful substance emissions.

#### 4.2.1.4 Combustion chamber enclosing construction components

The oxygen portion in the molecule of biodiesel (ca. 11 %) [7] is the reason for an improved combustion process with the application of biodiesel and therefore for significantly lesser soot. Diesel fuel related layering of the construction components enclosing the combustion chamber are likewise reduced. Laboratory tests confirm that the use of biodiesel does not result in an increased coking of the pistons and piston rings. Neither do the contact surfaces of the cylinder show any biodiesel-specific excessive wear marks [34]. This can only be achieved on condition that high quality production standard fuel is applied since, for example, incomplete transesterification can cause coking in the combustion chamber. Thus a bio component diesel fuel with up to 5 vol-% does not constitute a risk of increased formation of deposits or of wear as compared to mineral oil based diesel fuel.

*Recommendation*

The application of standardised biodiesel portions up to 5 vol-% in diesel fuel does not bear any risk of layering or excessive wear. A close inspection of the construction components enclosing the combustion chamber within the measures of regular servicing and maintenance intervals is recommended so as to ensure direct reaction to any changes in behaviour (wear, deposit) as common with diesel fuel.

### 4.2.1.5 Exhaust gas system

The exhaust gas system may include particle filters or catalysts. The particulates and soot particles of biodiesel exhaust gas differ from those of mineral oil diesel fuel. They contain a bigger soluble portion and are therefore easier to degrade in the catalyst system [7]. The application of oxidation catalysts supports avoiding the smell typical of heated or burned edible oils. Studies have shown that with the use of biodiesel the dimensioning limit (crankcase oil thinning) of the diesel particle filters may be exceeded so the application of filters needs to be checked on [12, 14]. With the use of standardised fuel after DIN EN 590 no additional measures related to particle filters and catalysts should have to be taken.

With the use of biodiesel blends of higher than 5 vol-% biodiesel in the fuel up to 100 %, particle filter manufacturers have to give their approval. In some cases the permission for the application with biodiesel have already been given [32, 33].

*Recommendation*

If standardised biodiesel of 100 % or as addition to mineral diesel fuel is applied, it is possible to integrate oxidation catalysts, which is recommended with respect to the reduction of harmful emissions. The fitting, respectively retrofitting of diesel particle filters requires clarification of their applicability and should be inquired for with the manufacturer, at least for the application of biodiesel portions above 5 vol-% in the fuel. If necessary, the diesel particle filters need to be exchanged. Appropriate filters are available. Moreover, compliance with the dimensioning limit values for diesel particle filters (oil thinning) must be ensured.

### 4.2.1.6 Lubrication oil system

Due to the tribological pairing of piston and cylinder liner a certain portion of the fuel can always be found in the crankcase oil. As biodiesel has a high evaporations point, it does not evaporate but remains in the crankcase oil and can start interacting with the it. Thus an enrichment with biodiesel, running straight proportionally with its percent by volume, is likely to occur [12, 14] .

Possible effects of crankcase oil thinning with biodiesel are :

- impairment of tribological characteristics
- excessive stress on addition of engine oil additives
- formation of deposits
- damage of catalyst
- excess of dimensioning limit for diesel particle filters

In a review of lubrication oil thickening with RME- operation [30], it is stated that in engine tests and analyses of used oil up to RME- portions from 10 vol-% to 20 vol-% in the engine, no drawbacks have been found.

Due to possible interactions, shorter exchange intervals for crankcase oil and oil filters are prescribed by the manufacturers for the engines that are permitted to and operate on 100 % biodiesel or blends of biodiesel–diesel. The operational instructions of the manufacturers for biodiesel approved engines have to be taken into account.

The oil change intervals are not influenced by the blending of 5 vol-% biodiesel and standard diesel fuel after DIN EN 590.

*Recommendation*

It is recommended to check regularly on the penetration of biodiesel into the crankcase oil because of possible interaction. This can be done by analysing the composition of the crankcase oil within the exchange intervals so as to react on time to the possible deterioration of the quality of the crankcase oil if necessary.

### 4.2.2 Boiler plants

Biodiesel and other bio component fuels have hardly been applied so far with boiler plants because of the little economic advantage involved. Just recently, with latest developments of oil-burning engines, boiler plants for these fuel qualities have been on offer.

When applying biodiesel in boiler plants, the same parameters and their characteristics have to be considered as with its application with engines. This applies in particular for the use of nonferrous heavy metals and elastomeres [29] and for the fuel stability at storing. Studies on the formation of deposits with the use of 5 vol-% biodiesel in the heating oil [35] show that the thermal boundary conditions of the heat generator have to be modified to suit the blend. Under the same evaporation conditions, they formed a tenfold larger mass of deposits as compared to heating oil without a portion of biodiesel, which even increased with lower oxidation stability.

*Recommendation*

With boiler plants, the application of a fuel blend with up to 5 vol-% biodiesel portion causes an increased formation of deposits on the boiler, which has to be taken into consideration and tended to within the periodical maintenance and servicing intervals. Service- and authorised repair shops can remove these deposits without substantial additional costs. As for seals, filters and likewise storage apply the same recommendations as given in chapter 4, paragraphs 2.1 and 2.3.

### 4.2.3 Storage on board

When storing biodiesel on ships, there are on the one hand, changes of fuel properties (fuel stability), on the other hand, potential effects of the fuel on construction components (solution properties) to be taken into account. Therefore, guidelines for the proper storage of 100 % biodiesel have been edited by Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V. [8, 31], which include the following items:

- Apply RME- resistant sealing surfaces and tank coating.
- If an old tank is to be used for storing (mineral oil diesel- RME) it needs to be emptied completely and undergo a dry cleaning.
- Clean tank every second year.
- Use biodiesel-resistant materials for seals and petrol pumps, respectively screwed pipes.
- Choose biodiesel-resistant petrol hose.
- Avoid components of zinc or copper and likewise coppery alloys. Zinc layers are partly dissolved and can form soap, copper functions as oxidation catalyst.

An inland navigation-specific situation arises with the fitting and the position of the tanks on the vessel. Hence formation of layers with different temperatures are likely to occur between the outer surface of the tank, bordering the rump of the ship and its inner surface, lying inside. In case the long-term study of this issue by the IWO does not provide siutable data, it is imaginable to achieve more exact results in long-term studies carried out under defined, reproducible conditions. .

The effect of biodiesel ratios in the mineral diesel fuel have not been satisfactorily explained. It can be assumed that with increasing biodiesel portion, seals and layers of biodiesel- non-resistant material are being affected and that in older engine plants on stock existing deposits are dissolved, which subsequently causes fuel filters to soil. Such problems have occurred in the field at storing, when blends of up to 5 vol-% have been stored [2].

High temperatures, frequent exposal to atmospheric oxygen, UV radiation and contact with nonferrous heavy metals are the reasons for a faster ageing of biodiesel compared to conventional diesel fuel. As countermeasures, oxidation stabilisers are added during the production process. The presence of water can lead to problems due to hydrolysis and microbial infestation RME is hygroscopic and has a certain buffer capacity (higher than diesel fuel), which reduces the formation of free water and with it creates unfavourable conditions for the development of the micro organisms. If free water exists, an increase of "biological activities" is likely to occur due to the biological components [12]. This may happen, for example, with great temperature variations and formation of condense water.

When in keeping with the guidelines for storage and storing technology, biodiesel can be stored for a period of up to one year without showing substantial losses in quality. In studies on storing pure biodiesel and diesel fuel with an RME- portion of 10 vol-% [13], storage in underground tanks, metal, respectively PE (temperatures ca. 5°C) over 96 weeks has proved unproblematic. In sealed-off spaces, the peroxide number of the blend as a measure of the oxidation-related deterioration did not at all or hardly change, whereas it increased with pure biodiesel to >50meq/kg, starting after 40-48 weeks.

Outdoors, with great temperature variations and additional exposure to light, substantial reactions both with the blend and the pure biodiesel were found after 8, respectively 18 weeks.

Contrary to underground tanks, which ensure proper storage, fuel tanks on board are exposed to major temperature variations and to the formation of condense water.

To what extent these specific conditions, which are different from storage on land, affect the storing parameters of fuel quality, needs to be further examined. Currently, further studies into this issue are being made at IWO - Institut für wirtschaftliche Ölheizungen – within the frame of a long-term study.

*Recommendation*

In order to keep the quality parameters high, diesel fuel with biodiesel portions should be stored in sealed-off spaces, cool and dark. As long as no new insight has been gained on the behaviour and fuel stability of mineral fuels with varying biodiesel portions from the long-term test at IOW and other studies, recommendations on the storage of 100 % biodiesel, for example, those given by Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V. [31, 37] see above), should be followed. Especially studies on the storage conditions on board of inland navigation vessels (temperature variations) are of great importance.

These could be best realised within the context of the introduction of bio component fuels. After changeover to fuels with bio components, these fuels have to be checked continuously as to ensure immediate reaction to noticeable interaction and deterioration of fuel qualities, for example, by after layering with biodiesel-resistant material. These measures are to be carried out by authorised service- or repair shops.

## 5. Summary

Basically, it can be stated that in keeping with, respectively realizing the recommendations given in chapter 4, older engines and boiler plants in the German inland navigation can be run on both low sulphur, respectively sulphur free diesel fuels or heating oils and blends with a bio component portion of up to a maximum of 5 percent by volume according to present experiences. Special attention has to be paid to securing the standardised fuel quality parameters at bunkering and storing on board.

**Low sulphur, respectively sulphur free fuel**

The findings of numerous studies on the use of low sulphur fuels have confirmed their unproblematic applicability in engines and boiler plants. Essential explanations have been given in chapter 4.

Engine plants

Special attention has to be paid to secure the lubricity of the fuels, in particular to maintain the functionality of injection pumps and its components. Here exist construction related boundary conditions especially for engines of lesser power, which have be considered. Due to the great variety of most different engine types installed on board the German inland fleet, just little technical data on them are available. This can result in operation-technological disturbances in a few cases which can, however, be dealt with at little expense by authorised servicing- and repair shops during the periodical maintenance measures.

Equally important is to keep in mind that a changeover to different fuel qualities always requires a new assessment and realisation of the recommendations given in chapter 4 for the respective construction units and components of the engine plant.

Boiler plants

Operational problems of boiler plants when run on low sulphur, respectively sulphur free fuels are unlikely to occur apart from trivial disturbances due to the “metal dusting” effect (see chapter 4), which can be cleared at low extra costs by authorised service- and repair shops.

**Addition of bio component fuels**

Biodiesel is added to a mineral diesel fuel up to 5 percent by volume at the stage of the mineral oil industry in compliance with DIN EN 590. Higher portions are obligatory to mark.

Engine plants

This standardised fuel containing a 5 vol-% biodiesel portion can be applied in engine plants when the given recommendations are realised. The blending of standard heating oils after DIN 51603, respectively the Dutch VOS specification with a biodiesel portion of 5 percent by volume should not bring about any operational problems.

In accordance with the recommendations, in detail explained in chapter 4, the following factors have to be considered and, if necessary, modifying measures have to taken to adapt the engine plant on board:

- check on a noticeable reaction of the sealing materials,
- check on the fuel filter after change-over and shortened filter change intervals if needed,
- check on the combustion chamber enclosing components and of the elements of the fuel injection system against abnormal behaviour compared to common diesel fuel behaviour,
- check on the crankcase oil against possible impairment of its properties caused by thinning with biodiesel,
- check on the fuel tanks and realisation of the recommendation given by Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V for storing ,
- check on the applicability of diesel particle filter,

The inspections should be carried out within the periodical maintenance and servicing check by authorised service- and repair shops. Substantial additional costs are not to be expected.

Boiler plants

The application of a fuel blend with up to 5% ratio of biodiesel in boiler plants is likely to lead to increased layering in the boiler, which are easily to remove by authorised service- and repair shops during the periodical maintenance measures at low additional costs. For about one year a long-term study about the application of bio component fuels in boiler plants has been on at Institut für wirtschaftliche Oelheizungen (IWO) e.V. , whose results have not been available for assessment so far. A fundamental restriction on the operation-technologial applicability of standard diesel fuel with up to 5 percent by volume in boiler plants is not to be expected..

<u>storage</u>

A specific issue related to the application of bio component fuels in inland navigation is the conditions for storing and preparation of the fuels on board. At storing specific boundary conditions need to be considered with respect to storing duration and temperature variations and likewise the coating of the storage tanks, which all may make the application of those fuels on board problematic. Comparable studies are going on for the boiler plant industry, but have remained so far without any final results. From the application of bio component fuels in road traffic, no storage-related problems have become known of due to the realization of the recommendations of Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V.

**References**


/1/ Erarbeitung von Verfahren zur Ermittlung der Luftschadstoffemissionen von in Betrieb befindlichen Binnenschiffsmotoren
FE Vorhaben Nr. BfG/M44/2001/968/1142/6/00
Bundesanstalt für Gewässerkunde, 2001

/2/ Studie zur Kraftstoffverträglichkeit bei älteren Binnenschiffen (Kessel/Heizung)
Bundesverband der Deutschen Binnenschifffahrt e.V., Juni 2007

/3/ Flüssige Brennstoffe - Heizöle
DIN 51603-1, September 2003

/4/ Auswirkungen des Zusatzes von Rapsmethylester (RME) auf die Schmierfähigkeit von schwefelarmen Dieselkraftstoff nach DIN EN 590 (neu)
Universität Rostock , FKZ: 99NR048, Juni 2001

/5/ Untersuchung zu FAME in Dieselkraftstoffen
DGMK Forschungsbericht 639, Juli 2006

/6/ Vergleich von Shell Mittel-Destillat, Premium- Dieselkraftstoff und fossilem Dieselkraftstoff mit Rapsölmethylester
Munack,A. u.a., FAL Bundesforschungsanstalt für Landwirtschaft, Dezember 2005

/7/ Biodiesel Flowerpower „Fakten - Argumente – Tipps“
ufop, 1/2004

/8/ Anforderungen an FAME aus der Sicht der Produktqualität
AG Qualitätsmanagement Biodiesel e.V., November 2005

/9/ Standardisierung von Rapsöl als Kraftstoffuntersuchung zu Kenngrößen, Prüfverfahren und Grenzwerten
Forschungsbericht Agrartechnik, Dissertation Edgar Remmele, 2002

/10/ Studie „Einsatz von Pflanzenölen in dezentralen Energieinseln unter besonderer Berücksichtigung der Problematik „Schwellenländer“
IBZ Hohen Luckow e.V. ; April 2005

/11/ Einsatz von biogenen Kraftstoffen in der Landwirtschaft
Dr. agr. Hans-Gerd Brandt, Pflanzenöltagung 30.11.2005

/12/ Bericht der Bio- Task- Force des FAM AA 632 zur Normung von Otto- bzw. Dieselkraftstoff mit max. 10% Ethanol bzw. FAME
Beimischung von Biokraftstoffen
Bericht der FAM AG „Beimischung von Biokraftstoffen, Mai 2007

/13/ Verwendung von Rapsöl zu Motorentreibstoff und als Heizölersatz in technischer und umweltbezogener Hinsicht
Landtechnik- Bericht Heft 15, Landtechnik Weihenstephan, 1997

/15/ Ölbrenner – Stand der Technik und neueste Entwicklungen
herrmann – Öl- und Gasbrenner, Nov. 2005

/14/ Motorölverdünnung durch Biodieselanteile bei Fahrzeugen mit DPF-Abgasnachbehandlung
VDA Arbeitskreis Betriebsstoffe, 15.09.2006

/16/ Ist schwefelarmer Kraftstoff eine Herausforderung für den Zweitakt-Schiffsdieselmotor?
Finn Q. Jensen, Schiff & Hafen 7/2005

/17/ Aerosolmassenspektronomie – Messung, verkehrbedingte Partikelemission
Schneider, J.; Drewnik, F. – Max-Plank- Institut für Chemie, Mainz, 2006

/18/ Umweltverträglichkeit der Binnenschifffahrt, CREATING NEWS
www.creating.nu, Oktober 2006

/19/ Geringere Umweltbelastung durch verbesserte Fahrzeugbetriebsstoffe
Shell Technischer Dienst, September 1996

/20/ Heizölqualitäten- Schweizerische Normen- Vereinigung
Normblatt 181160- 2, Mai 2006

/21/ Bundesregierung und Mineralölwirtschaft
Ein guter Tag für den Umwelt- und Klimaschutz
Ölheizung aktuell, Seite 5. Januar 2007

/22/ Rapsölmethylester in dieselmotorischer Verbrennung – Emission, Umwelteffekte, Optimierungspotenziale
FAL Sonderheft 233, 2002

/23/ Ergebnisse der Flottenerprobung beim Betrieb von Fischerbootenmit RME auf der Mecklenburgischen Seenplatte
Dr.-Ing. Hans-H. Maack, Universität Rostock
aus dem Tagungsband „Biodiesel & Sportschifffahrt in der Euregio Bodensee“, 24.09.01

/24/ Einsatz von alternativen Kraftstoffen in MTU Motoren
MTU, Juni 2006

/25/ Verwendung von Bio- Kraftstoffen in Massey Ferguson Traktoren und Landmaschinen
Technische Information Landmaschinen, April 2004

/26/ Einfluss Biodiesel auf NBR
Daimler Chrysler, Oktober 2006

/27/ Compatibility of NBR with Diesel/ RME/ FAME
GM Engineering Task Force Bio Fuels, Januar 2007

/28/ Erkennung des RME- Betriebes mittels eines Biodiesel- Kraftstoffsensors
FAL Bundesanstalt für Landwirtschaft, Sonderheft 257, November 2003

/29/ Ölbrenner – Stand der Technik und neueste Entwicklungen
herrmann – Öl- und Gasbrenner, Nov. 2005

/30/ Thuneke, K.; Wilharm, T.; Stotz, K.: Untersuchungen der Wechselwirkung zwischen Rapsöl als Kraftstoff und dem Motorenöl in pflanzenöltauglichen Motoren, Juni 2005

/31/ Biodiesel Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V.
Merkblatt für die Lagerung von Biodiesel (FAME) in Selbstverbraucheranlagen (SVA) oder Eigenverbrauchsanlagen (EVA), Mai 2003

/32/ EMINOX FBC- Diesel- Partikel- Filter- System
MOBAS- Ein Unternehmen der LARAG Gruppe, www.larag.com, Dezember 2005

/33/ BlueTec mit SCR- die bessere Alternative
Abgassystem mit Zukunft für EURO4 und EURO5
Mercedes- Benz Omnibusse, www.mercedes-benz.com, November 2005

/34/ Biodiesel & Co.
Biokraftstoff-Gesetzgebung, Markentwicklung, Forschung und Entwicklung
Ufop- Bericht 2005/2006

/35/ Ablagerungsbildung beim Einsatz von 5% Biobrennstoff- Blend (FAME) in stationären Verbrennungsanlagen und in einem Tiegelofen
Dipl.-Ing. A. Fischoeder, OWI GmbH, April 2006

/37/ Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V.
Merkblatt für den Umgang mit Biodiesel in Tankstellen
Stand Mai 2004

Ergänzende Literatur


/a/ Tiefentschwefelung von Mineralölfraktionen durch Extraktion mit ionischen Flüssigkeiten
Dissertation von Jochen Esser, Universität Bayreuth, Januar 2006

/b/ Kraftstoff Dieselmotor / Additive
www.Motorlexikon.de, Juli 2007

/c/ Perspektiven für Anforderungen an Abgas- und Partikelemissionen aus Dieselmotoren in der Binnenschifffahrt
Workshop 2000, Zentralkommission für die Rheinschifffahrt, 29.03.2000

/d/ Motorenöle
www.umweltbundesamt.de, November 2006

/e/ Energieeinsparung und CO2- Minderung durch breite Markteinführung von schwefelarmen Heizöl und Öl- Brennwerttechnik
Gemeinsame Erklärung von Bundesregierung und Mineralölwirtschaft, Berlin 15.01.07

/f/ Information der Fachpresse, Runder Tisch der Zentralkommission für die Rheinschifffahrt (ZKR) „Auf dem Weg zum schwefelarmen Kraftstoff in der Europäischen Binnenschifffahrt, Straßburg , 3.Mai 2007

/g/ Possible Transition to Ultra Low Sulphur Diesel
P.G. van der Zanden, Stichting Projecten Binnenvaart, Bureau Innovatie Binnenvaart. Mai 2006

/h/ Review of Directive 98/70
Ian Hodgson, European Commission, Brüssel, September 2005

/i/ Kraftstoff Dieselmotor / Additive
www.Motorlexikon.de, Juli 2007

/j/ Low Sulfur Fuel: The Impact of the Marine Industry
Exxon Mobil, Mai 2005

/k/ The Impact of Changing Marine Sulphur Legislation
Exxon Mobil, Mai 2005

/l/ Statement of Mr. Bert de Vries on behalf of inland navigation sector within CESA the Community of European Shipyards' Associations, Oktober 2006

/m/ Low Sulphur Fuel for IWT, The Position of the Netherlands
CCNR Round Table Sulphur, 3 May 2007, Martin Koopmans

/n/ Considerations on Low-S Fuel for Inland Waterway Vessel Engines
CCNR Roundtable, Strasbourg, 3. May 2007, www.euromot.org

/o/ Gelbe Energie für Binnenschiffe, Dipl.- Ing. Peter Pospiech
Binnenschifffahrt-ZfB- Nr. 1 / 2 – Januar/ Februar 2007

/p/ Richtlinie 98/70/EG des Europäischen Parlamentes und des Rates, 13. Oktober 1998 über die Qualität von Otto- und Dieselkraftstoffen und zur Änderung der Richtlinie 93/13/EWG des Rates

/q/ Vorschlag für eine Richtlinie des Europäischen Parlamentes und des Rates, zur Änderung der Richtlinie 98/70/EG, Nr. xx/xx/2006, 2006

/r/ Dritte Verordnung zur Durchführung des Bundes- Immissionsschutzgesetzes, 24.06.2002 BGBL S. 2243

/s/ Schwefelfreier Kraftstoff
www.kfztech.de, März 2007

/t/ Demonstrationsprojekt zum Rapsmethylester (RME)- Einsatz in umweltsensiblen aquatischen Bereichen
Prof. Dr.-Ing. U. Hansen, Abschlussbericht Universität Rostock 1997, Förderkennzeichen 95NR023-M

/u/ DRAFT- Entwurf einer B10- Spezifikation
VDA, Dezember 2006

/v/ FAME in Mineralölprodukten insbesondere HEL
DGMK Forschungsbericht 590, September 2001

/w/ Ermittlung eines technisch begründeten Grenzwertes für Schwefelgehalte in Heizöl EL zur Förderung des Einsatzes von Brennwerttechnologien in Ölheizungsanlagen
DGMK Forschungsbericht 601, Dezember 2002

/x/ Kriterienkatalog für Heizöl EL Additive
DGMK Forschungsbericht 646, Oktober 2004

/y/ Öl- Brennwerttechnik und regenerative Energien
IWO Institut für wirtschaftliche Ölheizung e.V., Juni 2007

/z/ Motoren innerhalb der weitgehend baugleichen Bonamare- Schiffsflotte
bonamare – Binnenschifffahrtsgesellschaft mbH, Juni 2007

/aa/ BDB begrüßt Beitrag zur Modernisierung der Flotte
Binnenschifffahrtsreport Nr. 1, 2007

/bb/ Kraftstoffe / Schmierstoffe – eingesetzt von MTU
Verband Schmierstoff- Industrie e.V., Juni 2007

/cc/ Die aktuelle Biokraftstoff- Gesetzgebung
ufap, Stand 01/2007-06-27

/dd/ Schmierfähigkeit Biodiesel
www.biodiesel.de, Juni 2007

/ee/ Biokraftstoffquotengesetz, Dezember 2006

/ff/ Erfahrung beim Einsatz von 5% Biobrennstoff- Blend (FAME) in stationären Verbrennungsanlagen
A. Fischoeder u.a., OWI GmbH, April 2006

/gg/ Produktspezifikation DK – Dieselkraftstoff schwefelfrei, max. 10ppm S
TotalFinaElf Deutschland GmbH, Februar 2003

/hh/ Heizöl EL – Produkt und Anwendung
IWO Institut für wirtschaftliche Ölheizung e.V., 2006

/ii/ Produkteigenschaften und Anforderungen für Heizöl EL
www.brennstoffhandel.de, Juni 2007

/jj/ 2- Stroke Crosshead Engine Lubrication- the Future here today
Lim, K.C.; Jahrbuch der STG 2002, Seite 264

/kk/ Kerokorr®LA
Produkt, www.chemicalportal.basf.com, Juni 2007

/ll/ Produktinformation – Diesel System Cleaner
Meguin GmbH & Co. KG, www.meguin.de, Oktober 2006

/mm/ CLAAS Erntemaschinen, Traktoren und Teleskoplader
Dieselmotoren – Hinweise zu RME
www.claas.com, März 2005

/nn/ Biodiesel B20 für Perkins Motoren freigegeben
Pressemitteilung 05.03.2007, www.perkins-de.com

/oo/ Biodiesel: Probleme aus der Praxis und Lösungsvorschläge
AG Qualitätsmanagement Biodiesel e.V., Juli 2006

/pp/ Biodiesel- Aussagen der Schlepperhersteller
ufop, Stand 10/06, www.ufop.de

/qq/ Bioheizöl- Brennstoff der Zukunft
Allgemeine Informationen Ölheizung und Bioheizöl, Hoval
www.hoval.de, Juni 2007

/rr/ Ermittlung der Schadstoffemissionen von Schiffsmotoren unter realen Bedingungen im Schwerölbetrieb Germanischer Lloyd, Forschungsberichte 0436 B, 1993