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GUIDELINES FOR DIESEL ENGINES LUBRICATION

IMPACT OF FUEL ON LUBRICATION

The International Council on Combustion Engines

Conseil International des Machines à Combustion

CIMAC is an international organisation, founded in 1950 by a French initiative to promote technical and scientific knowledge in the field of internal combustion engines (piston engines and gas turbines). This is achieved by the organisation of congresses and working groups.

It is supported by engine manufacturers, engine users, technical universitites, research institutes, component suppliers, fuel and lubricating oil suppliers and several other interested parties.

The National Member Associations and previous CIMAC Recommendations still available are listed in the back of this publication.

This document has been elaborated by the CIMAC Working Group „Marine Lubricants“ and approved by CIMAC in January, 2000.

FOREWORD BY THE PRESIDENT

Since residual fuel was first used in engines there have been reports of problems related to lubrication such as sticking pump plungers, undercrown deposits and piston ring wear. It has been hard for the engine operator to decide whether his solution lay with a change in the fuel used or a change to the lubricant. This document shows how the fuel used determines the lubricant required. It explains what factors have an effect and recommends what can be done to overcome specific problems.

This will be the 18th in the series of CIMAC recommendations which was started back in 1968. Since CIMAC is an international organization composed of representatives from the engine manufacturers, engine users, universities, research institutes, components suppliers, fuel and lubricating oil suppliers, classification societies and other interested parties it can be seen as being truly independent. I am therefore sure that this present document will be seen as a message which is truly independent and free of any commercial interest.

Future publications from this very active Working Group are expected to include:
- Lubrication of large high speed engine
- Oil degradation
- Gas engine lubrication

When these are available announcements will be made in the Press and on the Internet at www.cimac.com.

Our thanks go to all those members of the working group who put in so much effort and to their respective organizations for their support.

Stephen. G. Dexter, President
January 2000

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CONTENTS

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PREFACE

This document addresses the impact of fuel on lubrication of large diesel engines, both 2-stroke crosshead and 4-stroke trunk piston type, and identifies major areas of concern for which some guidance is offered.

1. INTRODUCTION

Fuels and lubricants are closely related in the operation of engines, in a multiplicity of ways, often complex and dependent on the design of the installation. Problem areas can be specific to the engine type, ie 2-stroke or 4-stroke, and may change over time requiring novel approaches to bring about solutions. This document covers areas that in recent times have either caused concern or acquired prominence in the light of certain industry developments. They are:

- Fuel pump plunger sticking;
- Piston undercrown deposit;
- Matching of lubricant basicity (BN) to fuel sulphur content;
- Low-sulphur fuel operation.

2. FUEL PUMP PLUNGER STICKING

The problem occurs mostly in **4-stroke engines** and has been reported in both marine and powergen installations. It is brought about by a thin,hard layer 10-20 µm thick, of deposit forming on the fuel pump plunger and barrel. It is seen frequently together with heavy sludge on the fuel rack and the lower plunger section, (Figure 1, Zones 1 and 2). Such deposits reduce clearances to the point of contact between plunger and barrel.

Incidences of pump plunger sticking were reported with some frequency in early 1990's, particularly in ship installations; (*Statistical information on perceived frequency and impact on operation is given Reference (1)).* On the whole, reporting has now decreased but it is still significant in some regions. Seen mainly as a design issue, the reduced incidence of sticking benefited not only from design changes but also from the latest generation of system oils with enhanced fuel compatibility.

2.1 Typical Circumstances

- Pump plunger lubricated by the system oil, operating as "sealing oil" and "splash lubrication".
- Engine running on residual fuel oil, (RFO), Also, switch over to distillate fuel from RFO before arriving in port or starting of the engine, if compatibility between the two fuels is poor.
- High content of fuel in the lubricant, thus fuel / lubricant interaction and fuel type / temperature have a major impact.
- Pattern of frequent engine stop-go with stops lasting some time, say over half-hour. This would point to some heat soak effect combined with enough time for the deposit to settle and consolidate on plunger and barrel.
- Design of plunger and barrel , a contributing factor in some cases.
- Standard fuel parameters are no guide to occurrence of problem though cracked fuels and higher asphaltenes content may make the problem worse.
- Deposit analysis shows predominance of organic material with relative low ash content containing fuel and lubricant elements.

2.2 Summing-up

- **Fuel quality is paramount but standard specifications are no firm guide.**

- **Fuel / lubricant compatibility is important.**

- **Practical tips:**
  - **After stopping the engine, continue to circulate fuel and lubricant for some time (say half-hour), followed by an additional period of same duration on lubricants only.**
  - **Consider changing the bunkering place or bunker supplier if possible.**

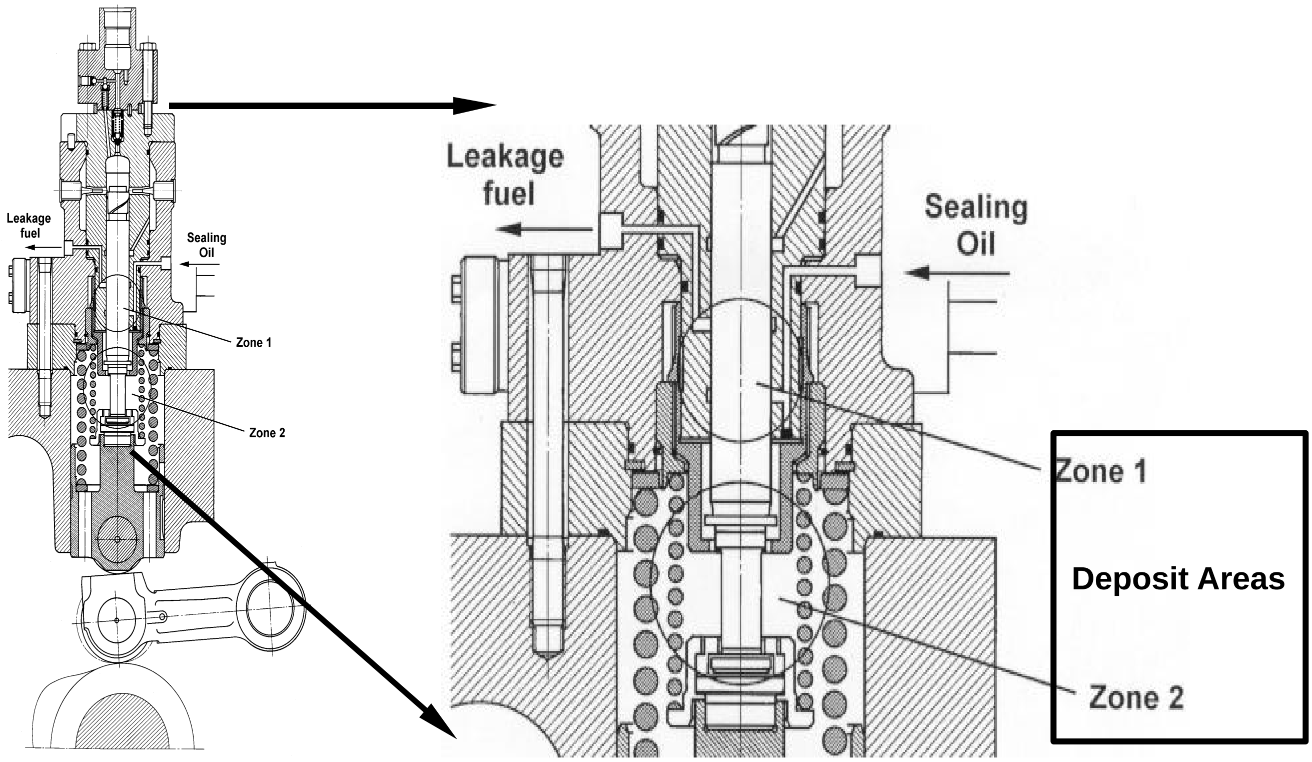

Fig 1 - Fuel Injection Pump

3. PISTON UNDERCROWN DEPOSIT

Piston undercrown deposit is seen primarily in **4-stroke engines.** It is carbonaceous material with some lacquer, reducing heat transfer through the piston crown to the system oil acting as coolant. Excessive levels of deposit can lead to piston distortion or cracking or seizure or hot corrosion. Anti-polishing rings may also be affected because of reduced clearance to piston crown land. (*See Reference (1) for statistical information on perceived frequency and impact on operation).*

Piston undercrown deposit may also be found in **2-stroke engines**, usually caused by contaminated system oil and an overloaded engine, a combination that increases the piston crown temperature.

3.1 Typical Circumstances

- Occurrence of deposit and its severity depend on piston undercrown design, material and temperature; also on coolant flow-rate and type of cooling eg spray vs shaker. The perception of undercrown deposit as an operational and maintenance problem varies significantly between engine designs, ranging from significant to practically nil. Also, there is no unequivocal evidence of significant differences between powergen and ship installations.
- Extent of lubricant contamination by raw fuel and fuel / lubricant compatibility have an impact.
- Deposit build-up is fairly rapid and then tends to stabilise ie no further large increases. Critical deposit thickness for adequate heat transfer is judgemental and varies between engine designs, (Figure 2).

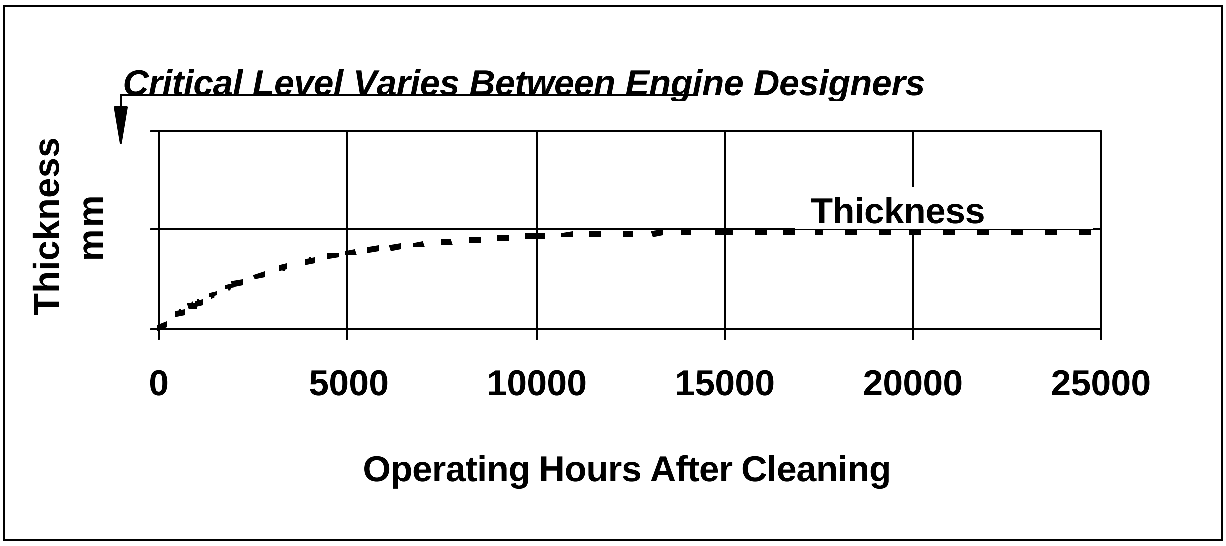

Fig 2 - Build-Up of Piston Undercrown Deposits

- Relevance of engine and undercrown design to deposit formation is such that certain installations may not suffer deposit problems even if the lubricant is contaminated with raw fuel, e.g. through fuel pump plunger leakages. On the other hand, deposits can occur even when there is no fuel contamination, pointing to inadequate thermal / oxidative stability of the lubricant for that particular application.
- Low specific lubricant consumption and smaller lubricant charges result in increased loading of the oil and increase the likelihood of deposit. The latter may also be related to lubricant quality.
- Latest generation of 4-stroke diesel lubricants is better equipped to prevent undercrown deposits.

3.2 Summing-up

- **Undercrown deposits can lead to serious mechanical problems.**
- **Deposit formation is influenced by piston design (through temperatures and coolant flow patterns), fuel contamination and lubricant quality.**
- **Latest generation of 4-stroke diesel lubricants are more likely to prevent deposits.**
- **For both 2-stroke and 4-stroke diesel engines, ensure that the oil in service remains within established quality limits at all times.**

4. MATCHING LUBRICANT BASICITY (BN) TO FUEL SULPHUR CONTENT

On a world-wide basis the sulphur level of residual fuel varies over the range 0-5% m/m, with very low number of deliveries with a sulphur level greater than 4%. Similarly for residual fuel the percentage with a level less than 1% is low.

Cylinder oil for 2-stroke engines and the lubricant for 4-stroke engines burning residual fuel have anti-corrosive properties to neutralise acidic combustion products. In that context the Base Number, (BN) provides a convenient benchmark of the anti-corrosive properties of the lubricant, as well as a measure of the reserve of alkalinity in the oil.

4.1 General Observations

In broad terms, higher BN oils are required for higher S-content fuels while lower BN levels are adequate or preferable for lower S-contents. There are, however, certain differences between 2-stroke and 4-stroke engines.

4.1.1 2-Stroke Engines

The generally accepted BN of the cylinder oil is 70. In the event of a high sulphur fuel oil, above say 3.5% m/m, the general recommendation is that either the cylinder feed rate is increased or a higher BN cylinder oil used. In a practical sense many vessels only have one cylinder oil storage tank and the availability of different BN cylinder oils is limited. While the feed rate can be increased with advantage to control corrosive wear, it does not follow that the feed rate can be reduced if the sulphur level falls. This is because the alkalinity reserve, expressed as BN, also contributes to other charateristics of the cylinder oil such as detergency and dispersancy. If the feed rate is reduced there may be insufficient levels of these characteristics. Also inadequate lubrication is likely to result in uncontrolled wear and deposits.

In the event of continued operation on fuel of less than 1% m/m sulphur, the engine manufacturers recommendations should be followed. If a low BN cylinder lubricant is not available because of operational reasons, then the normal feed rate should be maintained as recommended for 70 BN oil.

4.1.2 4-Stroke Engine

The alkalinity reserve of the new lubricant is selected on the engine design, typical sulphur of the fuels to be burnt and the oil consumption rate. The latter is determined primarily by the engine design and secondly by operating conditions. In any case, the engine builders should be consulted for their guidance.

4.2 Details of Relationship

The following is meant to highlight the complex perspective of the relationship and provide some practical guidance when trying to match lubricant BN to fuel S-content. It should also help clarify why for a given S-content, one might need to consider very different BN levels.

- S-content of fuel varies from bunkering to bunkering

S-content variations within 2%-points do not present particular lubrication problems for an oil of sufficiently high BN level. Larger variations resulting in fuel of very low S-content (around 1% or less) may need close monitoring of the engine, particularly a **crosshead type** lubricated by a standard 70 BN cylinder oil.

In the case of **trunk piston** engines, all is needed is to maintain the BN value of the oil-in-use above the level specified by the engine manufacturers. This may require some freshening up of the charge if significantly higher S-content fuels are bunkered.

- Same S-content may result in different amounts of acidic matters

The conversion rate of sulphur to sulphuric acid depends on operational factors such as combustion zone temperature and pressure as well as relative humidity of the scavenge air.

4.3 Total Available Basicity

Lubricants of same BN may result in different amounts of total available basicity. In fact, total availability of basicity, ie neutralization potential, depends on how much fresh lubricant (BN), is supplied to the engine either expressed as feed rate for cylinder oils of crosshead engines or Lube Oil Consumption (L.O.C.) hence rate of renewal of the oil charge in medium speed trunk diesel engines.

4.3.1 Feed Rate for Cylinders of 2-Stroke Engines

Concerning crosshead cylinder oils, there are of course engine builders' guidelines on feed rates for each type of engine. These are recommendations that recognise at the same time the need for the operator to adjust the feed rate as deemed necessary to meet the perceived need of the engine to maintain adequate lubrication, without impairing engine reliability. The use of a standard BN cylinder lubricant at the recommended feed rate will not cause any damage to the engine. Reduction of the feed rate may well lead to insufficient lubrication of the piston ring/linear interface with the possibility of accelerated wear.

Cylinder wall temperature or changes of it during operation, can impact on the matching of BN to fuel sulphur. In fact, the lower the temperature and the higher the combustion pressure - the more sulphuric acid will form resulting in an increased corrosivity.

4.3.2 Lube Oil Consumption in 4-Stroke Engines

Concerning lube oil consumption in trunk piston engines, the matter could become more independent of S-content when low to very low L.O.C. is experienced (0.50 down to 0.12 g/kWh). The engine builder requirement for a minimum BN for the oil-in-use translates into a demand for BN levels as high as 50-55 even if 30 or 40 would be adequate for the S-content of the fuel used. The key deciding factor for such higher BN levels is the impracticality or undesirability of frequent oil changes to maintain the BN above the required minimum level.

4.4 Summing-up

- **Base Number (BN) provides a benchmark of anti-corrosive properties of a lubricant.**

- **BN level of lubricant and Sulphur content of fuel are directly related in a broad way.**

- **When S-contents of bunkered residual fuel varies widely, then higher BN oils are acceptable for lower S-contents but lower BN oils do not provide adequate protection in conjunction with higher S-contents.**

- **Operational considerations other than neutralization of acidic compounds may demand BN levels in excess of perceived requirement of S-content.**

5. LOW-SULPHUR FUEL OPERATION

Operational difficulties are occasionally reported for 2-stroke and 4-stroke diesel engines running on low S-content fuels, notably Distillate Fuel and Residual Fuel Oil, (RFO). There is no industry definition of what constitutes a "low-sulphur" level though the broad understanding is as follows:

Distillate Fuel	(a)	Normal	0.2-1.0% occasionally 1.5%
	(b)	Low	<0.2%
	(c)	Very Low	<0.05%
Residual Fuel Oil	(a)	Normal	>1.0, typical 2.5-4.0
	(b)	Low	0.5-1.0
	(c)	Very Low	<0.5

5.1 Typical Operational Difficulties

Typical operational difficulties occasionally reported, are:

5.1.1 Distillate Fuel

- Lacquering of cylinder liners, (Conditions (b), (c)). Arguably related to fuel combustion (affected by high Final Boiling Point and / or inadequate air charge) and to low acid production that would help remove lacquer.
- Ash from lubricant resulting in deposits on piston crown and exhaust valves, (Conditions (b), (c)). A direct consequence of non-neutralised BN of the lubricant.
- Bore polishing, (Conditions (b), (c)). Related to excessive, hard deposit on piston crown land and disturbed oil film on rings and liners.

- Unexpected wear and deposits typically when running in crosshead engines (Conditions (a), (b), (c)).

5.1.2 Residual Fuel Oil

- For conditions (b), (c), difficulties are basically confined to crosshead type engines with:
  - abrasive wear in some instances with high BN cylinder oils, possibly related to significant hard deposits on the piston crown;
  - piston rings sticking or collapsing, sometimes traceable to the use of low BN cylinder oil leading to heavy deposit in the ring pack;
  - running-in, where some corrosive wear is required to smooth the surfaces.

5.2 Summing-up

- **Low and very low S-content fuels may result in poor engine condition, higher wear and deposits**

- **Practical tips:**
  - **latest formulation of high performance diesel lubricants (marine and automotive) can be effective anti-bore polishing products though not necessarily a solution for all engine and operational configurations;**
  - **use lowest possible BN lubricant for running-in compatible with maintaining engine cleanliness**

6. REFERENCE

(1) CEC 97-EL08 "Effects and determination of raw fuel dilution in marine crankcase lubricants".

7. ACKNOWLEDGEMENT

By endorsing this document, CIMAC acknowledges the work accomplished by the CIMAC Working Group "Lubricants" through its worldwide membership. A detailed listing of participating companies, institutions and associations is given on the inside of the back cover.

This document does not replace the recommendations of the engine builders or the advice of the oil suppliers, which may vary with designs and applications and take precedence over any CIMAC guidance. Users must evaluate whether the guidance in this document is appropriate for their purposes. CIMAC and the authors of this document make no warranty and shall have no legal responsibility for any consequence of the application of these guidelines.

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Other CIMAC Recommendations (Prices exclude packaging and postage!)

No. 1	Recommendations for Diesel Engine Acceptance Tests, 1968	Out of Print
No. 2	Recommendations for Gas Turbine Acceptance Test, 1968	Out of Print
No. 3	Recommendations of Measurement for the Overall Noise of Reciprocating Engines, 1970	Out of Print
No. 4	Recommendations for SI Units for Diesel Engines and Gas Turbines, 1975	Out of Print
No. 5	Recommendations for Supercharged Diesel Engines, 1971 Part I: Engine De-rating on Account of Ambient Conditions Part II: Engine Acceptance Tests	Out of Print
No. 6	Lexicon on Combustion Engines, Technical Terms of the IC Engine and Gas Turbine Industries, 1977	Out of Print
No. 7	Recommendations regarding Liability - Assured Properties, Publications and Fuels for Diesel Engines, 1985	DM 25.00
No. 8	Recommendations regarding Requirements for Heavy Fuels for Diesel Engines, 1986 (superseded by No. 11)	DM 25.00
No. 9	Recommendations concerning the Design of Heavy Fuel Treatment Plants for Diesel Engines, 1987	DM 40.00
No. 10	Recommendations regarding Liability - Assured Properties, Publications and Fuels for Gas Turbines, 1985	DM 36.00
No. 11	Recommendations regarding Fuel Requirements for Diesel Engines, 1990	DM 08.00
No. 12	Exhaust Emission Measurement - Recommendations for Reciprocating Engines and Gas Turbines, 1991	DM 25.00
No. 13	Guidelines for the Lubrication of Medium Speed Diesel Engines, 1994	DM 10.00
No. 14	Standard Method for the Determination of Structure Borne Noise from Engines, 1994	DM 08.00
No. 15	Guidelines for the Lubrication of two-stroke Crosshead Diesel Engines, 1997	DM 10.00
No.16	Guidelines for operation and/or maintenance contracts, 1999	DM 10.00
No. 17	Guidelines for Diesel Engines lubrication - Oil consumption of Medium Speed Diesel Engines	DM 10.00

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