

## THE DEVELOPMENT OF A TRUNK PISTON DIESEL ENGINE LUBRICANT

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The paper describes the development techniques used to produce a new trunk piston engine oil (TPEO) and compares its performance with currently available lubricants. The development of a superior quality trunk piston diesel engine oil involves many test techniques. To demonstrate high performance, use is made of both standard and developed tests and engine procedures in the laboratory.

Development equipment and test procedures are being modified constantly in an effort to simulate the conditions and anticipated problems associated with lubricants used in engines in their natural environment, however, regardless of the degree of performance quality achieved in the laboratory, the final arbiter for assessing the overall quality of any lubricant must be the machinery in which it will eventually be used.

### INTRODUCTION

An increasing use of medium speed diesel engines for both marine and land based applications is evident from published surveys. The marine applications are as prime movers in single or multiple units or as auxiliary engines, and it is to the marine service that attention has been directed although the same general conclusions apply to the land based engine. The competitive position of the medium speed diesel engine has been maintained and possibly improved by design changes leading to higher power ratings, increased dependability, and acceptable operating and maintenance costs. New engine designs commonly show power outputs in excess of 746 kW/cylinder with the figure of 1492 kW/cylinder being quoted more and more frequently. Published data clearly show this trend to higher output.

The high output medium speed diesel engine now and in the future will operate under conditions which stress the lubricant even more severely than hitherto; shipboard practice demands that the engine should be capable of extensive use between scheduled maintenance overhauls. In addition to these criteria further demands are placed on the lubricant by the use of the so-called economy fuels.

Because of the envisaged demand upon the lubricant in terms of temperature, pressure, centrifuge practice, and filtration requirements, the oil has to satisfy many more parameters than simply lubricating the moving parts. These requirements, not necessarily in order of importance, are:

#### *High Temperature and Oxidative Stability*

Thermal degradation of the lubricant may lead to the production of deposits in oilways or in the undercrown region. This can reduce the efficiency of the heat exchange process between the oil and the high temperature engine parts.

In the hostile environment of the internal combustion engine, the intimate contact of hot oil and air, catalysed by materials of manufacture particularly iron, promotes oxidation of the oil. If this is allowed to progress uninhibited, then lacquer, carbonaceous deposits, and the production of acidic material will result. This latter oxidation product is an unwelcome source of additive depletion and of corrosion.

#### *Compatibility with Materials of Construction*

The heavy duty bearings of high output trunk piston

engines incorporate mixtures of copper, lead, aluminium and tin. These materials can be attacked by the products of oil oxidation or, in some instances, by the lubricant additives themselves. Therefore it is important that the lubricant be non-corrosive and that provision is made to stifle auto-oxidation.

#### *Rust Protection*

Contamination of the lubricant with water is not an unusual occurrence on the marine environment. It arises from many sources ranging from engine coolant leaks, water ingress at the centrifuge (by accident or design) and, of course, it is produced in the combustion of the fuel. Also experience has shown that leakage of seawater into the non-pressurized parts of the system is an inevitable risk. It is possible to prevent rust corrosion of bearing journals and pins by using carefully selected additive components or by including a specific rust inhibitor in the lubricant.

#### *Extreme Pressure Wear*

In addition to corrosive wear, those areas where metal parts are subjected to high contact stress are likely to deteriorate. The wear occurring in a highly loaded valve gear is an example of this phenomena. Additives which combat this type of wear are generally known as extreme pressure (EP) additives and are being incorporated in current lubricants to an increasing degree.

#### *Balanced Purification Properties*

Contaminants in used lubricants such as soot, rust particles, depleted additives, abraded debris and water material may be removed by efficient centrifugal purification. Because of the inherent risk of water contamination, and the fact that the centrifuge itself contains water, it is essential that the additives in the lubricant are inert to hydrolysis. If this is not achieved, then serious additive loss, accompanied by abnormal centrifuge bowl fouling, will occur. It is desirable that any oil/water mixture does not become irreversible emulsified so that the entrained water cannot readily be removed from the system. Build-up of water in the oil will reduce the load carrying ability of the oil and increase the risk of bearing failure, and for obvious reasons it is important that

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large solid particles are also removed from the oil circulatory system.

This formidable list of requirements, which is by no means exhausted, can only be achieved by the use of carefully balanced modern lubricant additives.<sup>(1)</sup> It is fortunate that more than a single property can be catered for with some additives, for if this were not the case, the lubricant could conceivably contain upwards of twelve components and then the important task of obtaining the correct balance of additives would become almost impossible. Lubricants are available with outstanding properties in one area but poor performance in others. One example of this is the use of an anti-oxidant/EP additive which degrades "centrifugibility", engine cleanliness, and causes corrosive attack on bearing material. With the correct choice of additive components and adequate screening, problems of this nature need not arise.

### Deposit Control

The oil should have the ability to maintain the piston assembly in a clean condition (detergency) because mechanical problems such as piston scuffing and cylinder bore wear can result if the free movement of the piston rings is restricted; the minimum result of excessive deposit in the ring belt area is respiratory malfunction leading to reduced power output. In addition to the detergent action the lubricant must also have properties to ensure that solid material, passing down the cylinder walls in the oil film to the crankcase, remain in suspension (dispersancy), for by this means, soot and varnish precursors, produced in the combustion process do not deposit lower down the piston or, by agglomeration, settle out in other parts of the engine.

### Piston Ring and Linear Wear

Combustion of the fuel leads to the conversion of the sulphur in the fuel to sulphur oxides which under certain engine conditions<sup>(2)</sup> are converted to sulphuric acid. The acidic contaminant must be neutralized by the lubricant to prevent harmful corrosion of engine components such as piston rings and cylinder liners. Neutralization of sulphuric acid is usually accomplished by the incorporation in the oil of a soluble base. Acidic corrosion, is, by no means, the only source of ring and linear wear and other mechanisms may operate. A wear theory<sup>(3)</sup> postulates a combination of acid and abrasive wear resulting from fuel combustion, the wear increasing with the use of residual fuel and the resultant higher soot particle content.

#### LUBRICANT ADDITIVES FOR USE IN TPEO

Many excellent papers (e.g. references 4, 5, 6, 7) have been published in recent years on the general subject of additives for lubricants. An attempt is made in this section to review the mechanism by which deposits and wear occur in the diesel engine and which lubricant additives work to combat these undesirable effects.

### Engine Cleanliness

Deposits normally occur towards the crown of the piston, particularly in the top groove and on the upper piston lands. Analysis shows that they are largely composed of soot with an organic binder together with smaller amounts of inorganic material. A possible mechanism of diesel engine deposit formation is shown in Fig. 1.

Soot is produced as a result of fuel combustion. The amount of soot entering the piston ring zone depends upon injector/injection characteristics, combustion chamber design, fuel type, degree of wear in the engine, and is greatly increased by over-fuelling.

It is thought<sup>(8)</sup> that the organic binder results from two main sources:

- 1) oxidation of the lubricant base oil;
- 2) fuel combustion processes.

The deposits are readily controlled by a combination of detergent and ashless dispersant. The choice of an ashless component is important since it is advantageous if the dispersant itself does not contribute to the piston deposits.

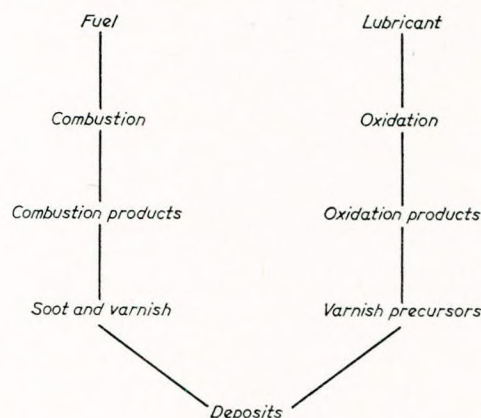


FIG. 1

Engine deposits have been shown to arise from some polyamine-derived dispersants by an oxidative mechanism. The deposit forming tendency of the dispersant itself can be eliminated by the correct choice of polyamine type and the manner in which it is incorporated into the molecule. In addition to the detergent/dispersant package it may be advantageous to include the correct type of anti-oxidant. This type of compound functions by preventing the chain process of auto-oxidation from occurring.

Already it can be seen that the lubricant designer is faced with a wide choice of additive types whilst considering control of deposit formation.

### Additives to Combat Diesel Engine Deposits

#### Detergent

Calcium/barium sulphonates,  
calcium phenates,  
barium phosphates,  
calcium salicylates.

#### Dispersant

Calcium sulphonates,  
calcium salicylates,  
ashless succinimide.

#### Anti-oxidant

Hindered phenols,  
zinc dialkyl (or aryl) dithiophosphate.

### Engine Wear

Engine cleanliness is a requisite function of the lubricant but an equally important area of investigation is that frequent cause of engine failure—wear. It should be appreciated, of course, that the build-up of engine deposits can contribute to wear, particularly of the piston ring and cylinder liner. Metal to metal contact may be prevented by ensuring that under all conditions a fluid film is maintained between the moving metal parts. This is readily accomplished by the lubricant providing that it is essentially free from other phases such as water. As the load increases, the fluid film can rupture, and separation depends upon the presence of a boundary lubricant film. Where the load is extreme, prevention of wear relies upon the existence of solid protective films formed by the reaction of the EP additive and the relevant metal surfaces.

Corrosive wear is largely the result of acid attack by blow-by contaminants on the working surfaces. These acids may be readily neutralized by alkaline additives such as the alkaline earth metal phenates or sulphonates. Once again, selection of additive is important, since some alkaline additives are known to be somewhat hydrolytically unstable. An interesting phenomenon, related to wear control, is the ability of ashless dispersants to control corrosive wear in the presence of high concentrations of mineral acid.<sup>(9)</sup>

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### Additives Used to Combat Wear in Diesel Engines

#### Corrosive Wear

Alkaline metal derivatives of:

- Sulphonic acids,
- sulphurized phenols,
- naphthenic acids,
- salicylic acids.

#### Adhesive Wear

Zinc dialkyl (or aryl) dithiophosphates, sulphurized compounds.

These then are the main areas of concern. The remaining parameters, such as abrasive wear, are controllable by removing the offending abrasive particles by efficient filtration or centrifuging. Other factors, such as rusting, bearing material compatibility, thermal stability and centrifugibility may be mastered by the use of high quality additive components and ensuring that no harmful interactions occur. This constitutes the all-important formulation balance.

#### THE EVALUATION OF MARINE LUBRICANTS

In any development programme the normal sequence of events would be:

- a) preliminary bench screening;
- b) evaluation of candidate oils in laboratory engine tests;
- c) testing in full scale engines under laboratory conditions;
- d) testing in full scale engines in the appropriate environment.

The paper discusses (a) and (b) but touches only briefly on (c) and (d) to complete the picture.

To obtain meaningful results experimental oils should be evaluated against lubricants having known performance in the full scale situation. Thus by modifying the laboratory test in terms of duration, and conditions of operation, it is possible to "fail" an oil of limited performance and thereby form a basis on which to improve. It is an overall superiority which is sought and not simply an oil having, for example, better diesel detergency. For this reason the authors have used several test methods to confirm performance not described by standard techniques.

Comparison is made between an experimental oil Cx with a range of alkalinity level or total base number (TBN) and known commercial marine TPEO of comparable TBN designated type A, B and C. This method of describing oils is one of convenience and is an attempt to classify oils roughly according to chemical type.

#### Type A

The initial answer to the problems of excessive wear associated with the introduction of high sulphur residual type fuel. Additive content provided mainly alkalinity.

#### Type B

An improvement over type A with the addition of a metallic detergent to the alkaline additive. Engine cleanliness improved without loss of acceptable wear control.

Both type A and B lubricants are still widely used with success in marine and land based service.

Present day highly rated engines operating under severe conditions of temperature and pressure, and using residual fuel require a lubricant having properties not normally met by either type A or B lubricants.

#### Type C

A fully compounded dispersant oil.

From a survey of commercial trunk piston engine oils conducted recently several features of interest are observed:

- i) a trend towards type C oils;
- ii) the bulk of TPEO depend upon calcium containing

- additive to contribute alkalinity;
- iii) some lubricants are compounded with antiwear additives.

Comparative data from several test techniques are tabulated. Commercially purchased samples drawn from types A, B and C are evaluated against the new lubricant coded Cx at equivalent TBN level. The Cx lubricant has been evaluated in the laboratory at all levels of alkalinity common to the marine trunk piston engine environment and found to be at least equal, but in many cases superior, to comparable commercial oils. The examples described here, are drawn from the range of lubricants commonly used in marine medium speed engines, i.e. up to ~30 total base number (E4).

#### A. HIGH TEMPERATURE AND OXIDATIVE STABILITY

A.1 Test Procedure:	Panel coking test.	
Method:	Modified US FTM 3462.	
Evaluation:	Lubricant coking tendency.	
Apparatus:	Splash chamber test set up as specified by FTM 3462 but equipped for cyclic lubricant splashing.	
Materials:	Aluminium alloy test panel 300 cm <sup>3</sup> lubricant sample.	
Condition:	Lubricant is splashed against polished and weighed test panel maintained at 315°C under the following conditions:	
	<i>a.</i>	<i>b.</i>
Test duration, h	5	24
Splashing cycle:		
	On	15
	Off	9
Inspection:	Weight in milligrams of coke deposit on panel.	

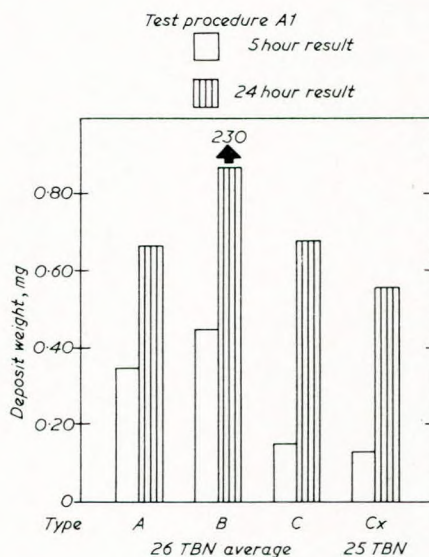


FIG. 2

A.2 Test Procedure:	Indiana stirring oxidation test.
Method:	JIS K 2514.
Evaluation:	Oxidative stability.
Apparatus:	Oil bath, 500 cc tall form sample beaker, glass varnish rod and stirrer with two 40° pitch, 2 cm diameter blades.
Materials:	32.25 cm <sup>2</sup> electrolytic copper and 64.5 cm <sup>2</sup> hot rolled steel catalysts. 250 cm <sup>3</sup> lubricant sample.

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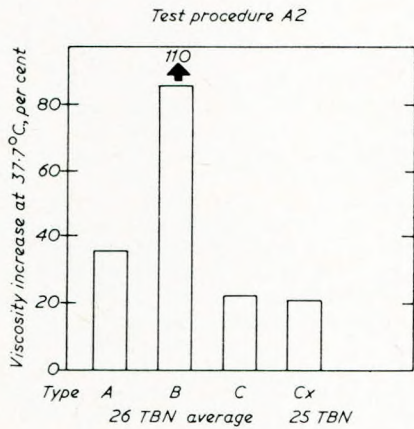


FIG. 3

Conditions: Sample and catalysts are heated in beaker with varnish rod to 165.5°C and aerated by stirring at 136.1 rad/s for 48h.

Inspections: Lubricant viscosity at 37.7°C and total acid number increase, varnish rod deposits rated as none, slight, medium or heavy.

A.3 Test Procedure: Oxidation test.  
Method: I.P. 48.  
Evaluation: Oxidative stability.  
Apparatus: Oil bath, air inlet and sample oxidation tube set up as specified by designated method.

Materials: 40 cm<sup>3</sup> lubricant sample.  
Conditions: Sample is heated to 200°C air blown at a rate of 15 litres/h for 6h, then removed from the bath and allowed to stand at ambient temperature for 12 – 18h. The procedure is repeated at 200°C and the lubricant examined 15–30h after completion of the second 6h oxidation period.

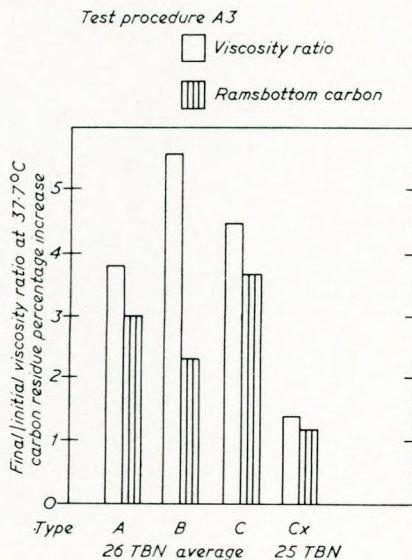


FIG. 4

Inspection: Final/initial viscosity ratio at 37.7°C and wt. per cent increase of lubricant Ramsbottom carbon residue.

A.4 Test Procedure: Petter W1 engine test.  
Method: I.P. 176 (extended).  
Evaluation: Viscosity increase at 37.7°C; connecting rod bearing corrosion (by wt. loss).

Apparatus: Single cylinder 470 cc Petter W1 laboratory gasoline engine with 85.0 mm bore, 82.5 mm stroke, 20° BTDC spark ignition and 5:1 compression ratio.

Materials: Fuel—DEF STAN 91-7/1 leaded gasoline. Lubricant—2 kg. Special copper lead bearing insert in connecting rod.

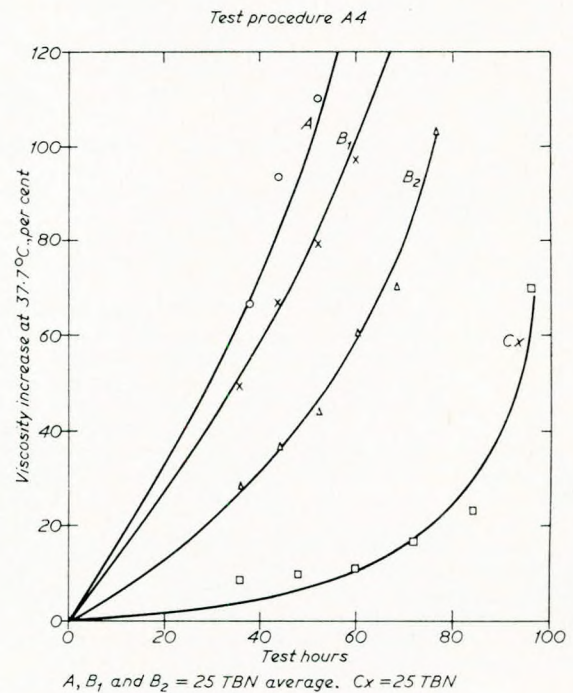


FIG. 5

Condition: After break-in procedure, endurance run is conducted under the following condition: Up to 100h dependent upon lubricant quality.

Test duration, h

Engine speed, rad/s 157.1.

Load, kW ~ 2.462.

Fuel consumption, g/min. 19.8.

Air/fuel ratio ~ 12:1.

Exhaust temp., °C 600 max.

Manifold depression, mm Hg 51.

Coolant outlet temp. °C 150.

Oil pressure, kg/cm<sup>2</sup> 0.56.

Coolant inlet temp. °C 137.5.

Oil charge, kg 1.

Make-up rate None.

Hot-spot temp., °C 200.

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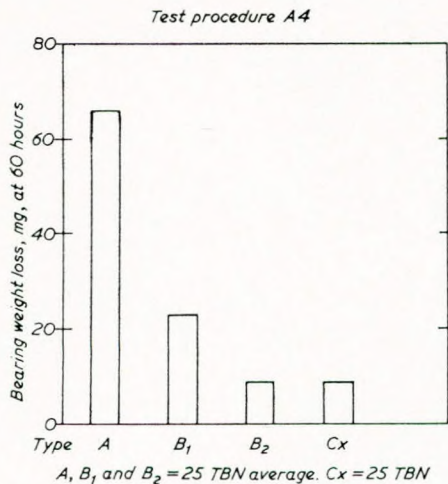


FIG. 6

**Inspections:** Viscosity at 37.7°C reported as per cent increase on 50 cm<sup>3</sup> lubricant samples (returned to crankcase) at 0 and 36h, and regular intervals thereafter depending upon the lubricant quality.  
Copper lead connecting rod bearing weight loss in milligrams at same intervals.

### B. COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

White metal crankshaft bearings and big-end connecting rod bearings together with phosphor bronze small-end bearings are likely to be the more sensitive materials in the engine crankcase. To evaluate lubricant/material compatibility Mirrlees Blackstone devised a bench test. The test is in common use and forms yet another link in the chain of development.

**B.1 Test Procedure:** Mirrlees bearing corrosion test.  
**Evaluation:** Lubricant grain boundary attack and incipient corrosion tendencies.  
**Apparatus:** Vented convection oven and 250 ml tall-form sample beakers with inert specimen hangers.  
**Materials:** Copper-lead, phosphor bronze, aluminium-tin and white metal specimens, cut from bearings and micro polished as specified. Four ~ 170 cm<sup>3</sup> lubricant samples.

TABLE I—TEST PROCEDURE B.1

Lubricant	TBN	White Metal	Phosphor Bronze
Type A (1)	Average 7	Pass	Pass
(2)	„	Borderline	Pass
Type B	„	Fail	Borderline
Type Cx	7	Pass	Pass

**Conditions:** The specimens are suspended in separate lubricant samples and the beakers, covered tightly with filter paper, held at 140°C for 100h.

**Inspections:** Specimen corrosion examined, and rated as:  
**Visual:** Any black adherence or flaking scale indicates failure; tarnish to blue interference discolouration is considered unacceptable.  
**Microscopic:** Any grain boundary attack or appreciable darkening of grains indicates failure.

### C. RUST PROTECTION

**C.1 Test Procedure:** Rust test.  
**Method:** ASTM D665/I.P.135.  
**Evaluation:** Lubricant rust inhibition properties.  
**Apparatus:** Oil bath, sample beaker and stirring set-up as specified by designated method.

TABLE II—TEST PROCEDURE C.1

Lubricant	TBN	Results
Type A	Average 26	Fail (moderate rusting)
Type B	„	Pass
Type C	„	Pass
Cx	25	Pass

**Materials:** Carbon steel test specimen 30 cm<sup>3</sup> synthetic sea water, 300 cm<sup>3</sup> lubricant sample.  
**Conditions:** After heating sample to 60°C and immersing polished specimen, water is added and stirring continued at 104.7 rad/s for 24h.  
**Inspections:** Specimen rusting rated as:  
Pass: No rust.  
Fail: Light rusting —1 mm spots, 6 max.  
Moderate rusting —5 per cent area max.  
Severe rusting —more than 5 per cent area.

### D. EXTREME PRESSURE WEAR

Advantage is taken to include a laboratory method extensively used by Japanese companies to define the performance of marine lubricants.

**D.1 Test Procedure:** SODA Four-ball wear test.  
**Method:** NDS XXK 2740 stepload.  
**Evaluation:** Lubricant extreme pressure wear inhibition.

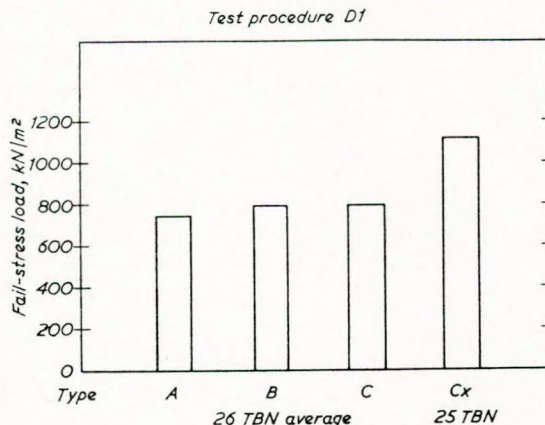


FIG. 7

## The Development of a Trunk Piston Diesel Engine Lubricant

Apparatus: SODA Four-ball testers.  
 Materials: Steel balls, 19.05 mm diameter and 61.5 to 66.55 Rockwell hardness C scale (H.R.C.) number as specified by JIS B1501, 70 cm<sup>3</sup> lubricant sample per run.  
 Conditions: Chucked ball is rotated at 20.9 rad/s and 49kN/m<sup>2</sup> (0.5 kgf/cm<sup>2</sup>) load against three stationary balls covered with 20–30°C lubricant. Load is increased by 49kN/m<sup>2</sup> (0.5 kgf/cm<sup>2</sup>) increment each minute until seizure occurs.

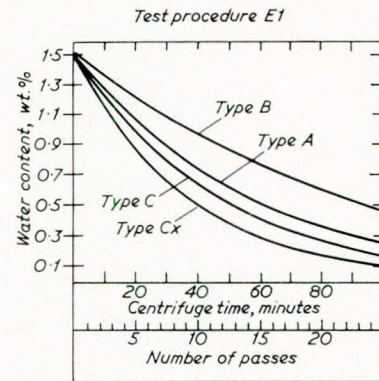
### E. BALANCED PURIFICATION PROPERTIES

This test in a laboratory size centrifuge was designed to compare lubricants in their ability to shed water. The method relates to the condition caused by leakage of fresh water into a marine crankcase lubricant, (the leakage subsequently stopped). The lubricant must obviously resist any tendency to form stable emulsion with the added water.

E.1 Test Procedure: Water shedding characteristics.  
 Method: AF.1A.  
 Evaluation: Fresh lubricant water separability properties.  
 Apparatus: Alfa Laval M.A.B. 103B-25 centrifuge, heated lubricant reservoir, pumps, valves and lines as indicated in Fig. 8.  
 Materials: ~ 15.9 kg lubricant sample, 1.5 per cent wt. of lubricant charge (0.238 kg) distilled water.  
 Conditions: Water is added to lubricant held at 75°C over a 1h period with continuous circulation

Inspections:

through a gear pump to ensure good dispersion. Centrifuge is started, sealed with water, and the contaminated lubricant is fed through the centrifuge at 60°C at a circulation rate of 270 litres/h. Test duration of 100 minutes (25 passes) commences when purified lubricant reaches reservoir. Lubricant samples (100 cm<sup>3</sup>) are taken at 0, 5, 10, 25, 50 and 100 minutes from the reservoir. Wt. per cent of water in lubricant samples.



Type A, B, C = 26 TBN average  
 Type Cx = 25 TBN

FIG. 9

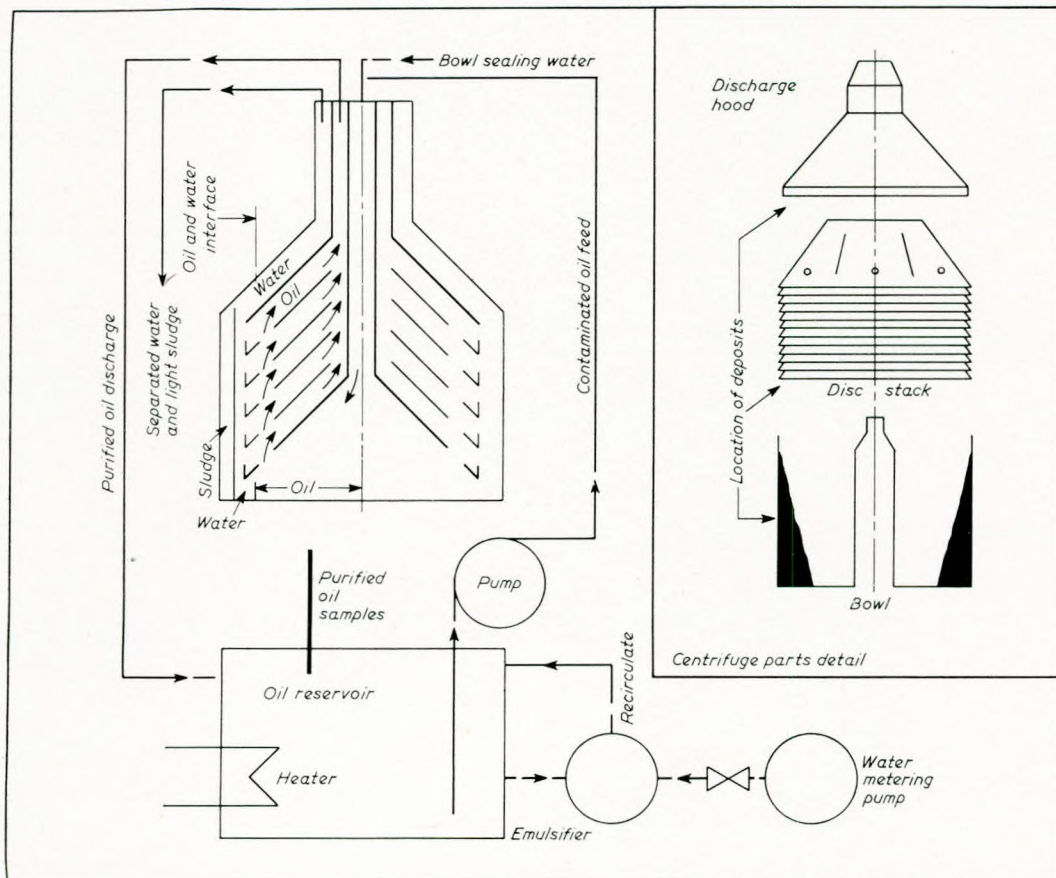


FIG. 8

## The Development of a Trunk Piston Diesel Engine Lubricant

Procedure E.2 was designed to evaluate in a laboratory size centrifuge the performance of a lubricant in the presence of a steady and continuous leakage of water. Performance is related to rate of TBN loss (alkalinity depletion) and deposits in the centrifuge which might impair the ability of centrifuge to separate oil and water clearly and rapidly.

**E.2 Test Procedure:** Centrifuge hydrolytic stability test.  
**Method:** AF.1B.  
**Evaluation:** Fresh lubricant alkalinity retention and emulsifying tendency.  
**Apparatus and Materials:** As E.1 except with 1.19 kg additional water.

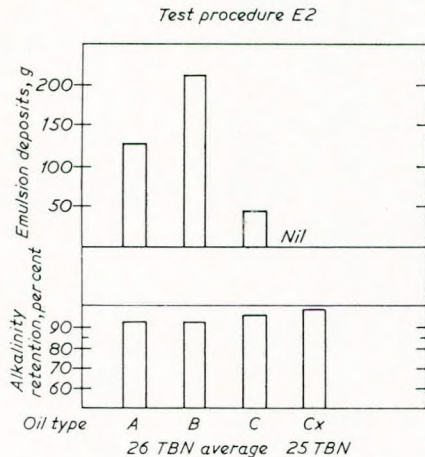


FIG. 10

**Condition:** As E.1 except test duration extended to 5h (75 passes). Water added continuously after initial "contamination" of 1.5 per cent wt. lub. charge at a rate of approximately 240 g/h. (1.5 per cent wt. of lub. charge/hour). Samples taken at hourly intervals.  
**Inspections:** TBN (method E.4) of lubricant samples and weight of centrifuge disc and bowl deposits (g).

From the two previous centrifuge evaluations on new oil, investigation into used oil characteristics is a natural sequel. The problem of oil quantity is overcome by installing a smaller centrifuge with a low working quantity requirement approximating to 4.54 kg. The centrifuge is used in conjunction with an engine test described under F.1.

The test evaluates the ability of lubricants subjected to soot contamination to suppress by means of a centrifuge the effects of a simulated water leak. At the same time the effects on engine deposit control are ascertained.

**E.3 Test Procedure:** Centrifuge purification test.  
**Method:** AF2.  
**Evaluation:** Effect of batch type purification on lubricant alkalinity retention, insolubles and engine deposit tendencies.  
**Apparatus:** Alfa-Laval MAB 102B-25 centrifuge, heated lubricant reservoir, pumps, valves and lines as indicated in Fig. 8.  
**Materials:** ~ 5 kg lubricant sample dependent upon oil consumption rate of engine test.

**Conditions:** Distilled water addition equivalent to 1 per cent of oil charge. Engine crankcase oil charge is removed after 60h of engine operation and placed in reservoir (Fig. 8). Water is added to lubricant held at 90°C over 30 min with continuous circulation through gear pump to ensure good dispersion. Centrifuge is started, sealed with water and contaminated lubricant is fed through the centrifuge at 70°C and a circulation rate of 13 litres/h. Test duration equivalent to 30 passes of the lubricant charge commences when "purified" lubricant reaches the reservoir. 100 cm<sup>3</sup> lubricant samples are taken as received from the engine and after centrifuging at 60h engine operating intervals. After centrifuging the oil may be returned to the engine crankcase.  
**Inspections:** TBN (method E.4) insolubles (method F.3) and other properties as required of lubricant samples. Engine deposits at 60h intervals.

The TBN or alkalinity of a lubricant is a measure of its ability to neutralize and thus deactivate potentially corrosive acids which otherwise cause engine wear by corroding cylinder liner surfaces and piston rings.

**E.4 Total Base Number Determination**  
**Method:** ASTM D2896/I.P. 276.  
**Evaluation:** Lubricant alkalinity determination.  
**Apparatus:** Potentiometric titrimeter, 250 cm<sup>3</sup> sample beaker and other equipment as specified by designated method.

TABLE III—METHOD E.4 (ALKALINITY RETENTION)

Test Time	Alkalinity Retention as Percentage of Original			
	21 TBN Average		24 TBN	
	A	B	C	Cx
Start	100	100	100	100
12	90.6	N.S.	82.9	95.0
24	85.9	N.S.	81.4	89.6
36	80.0	72.0	79.0	87.9
48	71.8	68.8	74.3	73.3
60	70.0	65.2	68.1	75.8
Cent	4.7	60.0	64.8	66.3
72	4.7	56.8	63.8	60.8
84	N.S.	50.4	50.5	47.1
96	2.4	47.2	44.8	46.3
108	0	34.4	31.0	40.0
120	0	34.8	33.8	41.7

**Materials:** Chlorobenzene and glacial acetic acid solvent, perchloric acid titrant and other reagents as specified. Maximum 20 g lubricant sample.  
**Conditions:** The dissolved sample is titrated with standard perchloric acid titrant and the

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Inspections: millivolt readings plotted against volume (cm<sup>3</sup>) of titrant. TBN of lubricant as calculated from the volume of titrant corresponding to the mid-point of the titration curve inflexion.

## F. DEPOSIT CONTROL

The choice of a laboratory evaluation engine was governed by engine availability and versatility. Financial consideration could not be ignored. The Caterpillar engine has been used in lubricant laboratories for some 25 years now and although its basic design is unchanged, different service groups allow variations in engine build to give a naturally aspirated engine or varying degrees of supercharging. The engine has only one cylinder and spare parts are readily available. Earlier laboratory work showed the potential of this engine.

**F.1 Test Procedure:** Modified Caterpillar 1A test with AF.2 (E.3) centrifuge.  
**Method:** IS-21-D.  
**Evaluation:** Effect of lubricant purification on deposit control in a diesel engine using residual fuel. Establish piston ring wear by weight and engine wear by lubricant iron content.  
**Apparatus:** Single cylinder, naturally aspirated 3.4 litre capacity, four-stroke Caterpillar 1Y, 7500 laboratory engine; 146.0 mm bore, 203.2 mm stroke.  
**Materials:** Fuel 1500 seconds Redwood No. 1 residual, sulphur content 2.5-3.0 per cent, lubricant 13.6 kg.

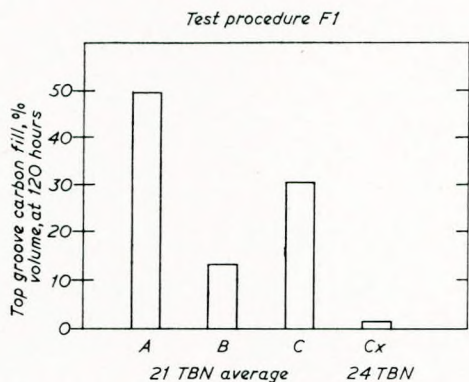


FIG. 11

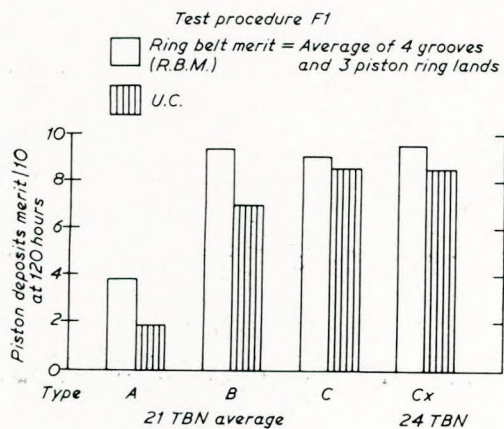


FIG. 12

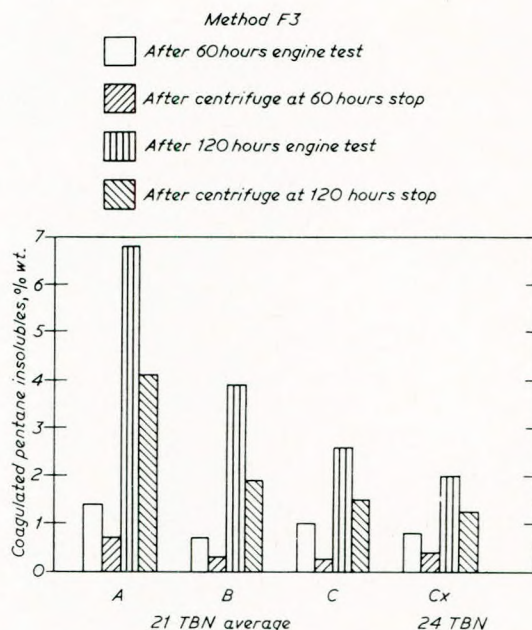


FIG. 13

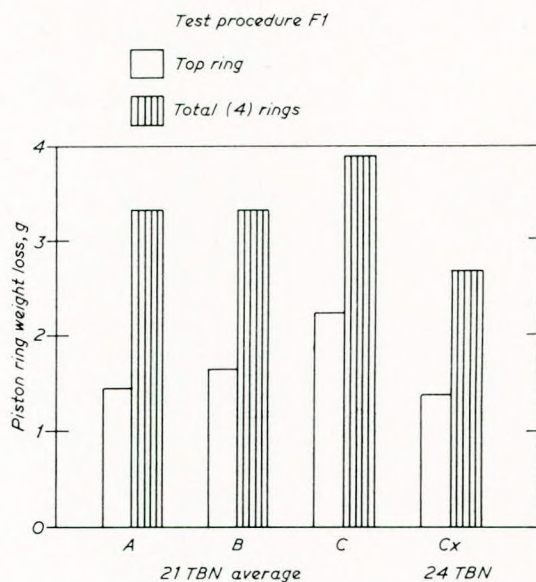


FIG. 14

TABLE IV—TEST PROCEDURE F.1 (IRON CONTENT)

Test Time	Iron Content During Test ppm			
	21 TBN Average		24 TBN	
	A	B	C	Cx
12	178	200	189	154
24	293	252	191	184
36	346	195	245	210
48	423	340	281	224
60	574	385	335	232
72	277	228	277	181
84	N.S.	272	325	251
96	361	378	393	287
108	394	365	439	345
120	436	390	499	382



## The Development of a Trunk Piston Diesel Engine Lubricant

Conditions: Two-hour run-in with one per cent sulphur distillate fuel. Change crankcase oil charge. Test proper starts when temperatures and pressures attained. Duration: Multiples of 60h. Oil charge: 6.8 kg, no make-up.

Speed: 104 rad/s.  
 Load: Approx. 15.7 kW.  
 Heat Input/min: 3292 ± 53 kJ.  
 Fuel Measurement: 500 g over 6.5 min ± 6s.  
 Coolant: 100 per cent Glycol.  
 Coolant Out: 121 ± 2°C.  
 Oil Temp. in Gallery: 64 ± 5°C.  
 Oil Pressure: 2.11 kg/cm<sup>2</sup>.  
 Air Temperature: Ambient.  
 Air Pressure: Atmospheric.  
 Fuel Temp. in line to injector: 95 ± 5°C.  
 Oil samples 50 cm<sup>3</sup> each 12h —no make-up. At 60h remove piston for rating (rings *in situ*). Drain all crankcase oil and subject to centrifuge (Procedure E.3). Return piston and lubricant to engine (no make-up) and continue for further 60h.

Almost continuous modifications to the running conditions of the laboratory naturally aspirated engine has resulted in the F.1 test procedure. Problems with piston scuffing in the high temperature environment and ring bedding in the short duration test have been largely overcome.

Temperature measurement using the Templog method shows the top groove temperature equates to that usually quoted for the Caterpillar 1G supercharged engine test viz. 240°C.

Four oils are compared using the engine/centrifuge F.1 test procedure and the oil consumptions average at 17 g/h with a "low" of 14.1 g and a "high" of 19.0 g.

### F.3 Insolubles Determination

Method: ASTM D893.  
 Evaluation: Lubricant pentane and benzene insolubles.  
 Apparatus: Centrifuge tubes, centrifuge rated at 600-700 r.c.f. at tube tip and other equipment as specified by designated method.  
 Materials: Benzene, pentane, coagulant and other reagents as specified.  
 Conditions: Sample is diluted to 100 cm<sup>3</sup> with chosen reagent, shaken until homogeneous and centrifuged for 20 minutes at room temperature. The supernatant liquid is decanted, the precipitate twice washed and centrifuged for 20 min and, the separated precipitate weighed after desiccation at 105°C for 30 min.  
 Inspections: Weight of precipitated insolubles.

When evaluating lubricants for eventual use in supercharged engines one is tempted to have reservations when ascertaining quality in naturally aspirated engines however acceptable the results may appear to be.

To strengthen the case of acceptable laboratory evaluation a further test series was conducted using an established laboratory engine supercharge procedure but using a more

critical fuel to encourage deposit formation in a short test time.

In order to ensure "scale", comparison is made between the experimental lubricant and three commercial oils in the lower TBN range.

F.4 Test Procedure: Modified OMD 113 (DEF STAN 91/22/1).  
 IS-75.  
 Method: Effect of lubricant on piston ring sticking. Formation of deposits on piston and rings. Establish piston ring wear by weight and engine wear by lubricant iron content.  
 Evaluation:  
 Apparatus: Caterpillar single cylinder four-stroke engine 1Y73 arrangement. stroke: 165.1 mm, bore: 130.175 mm.

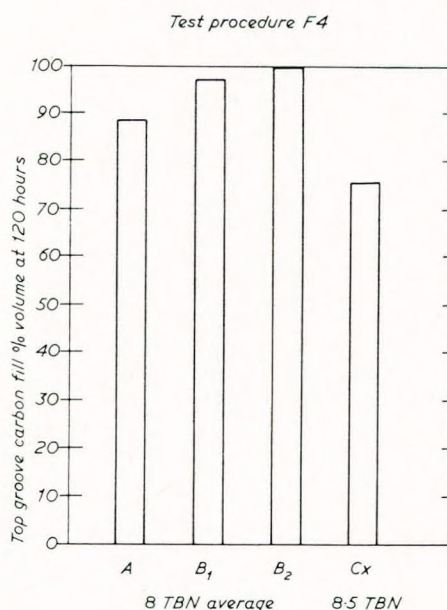


FIG. 15

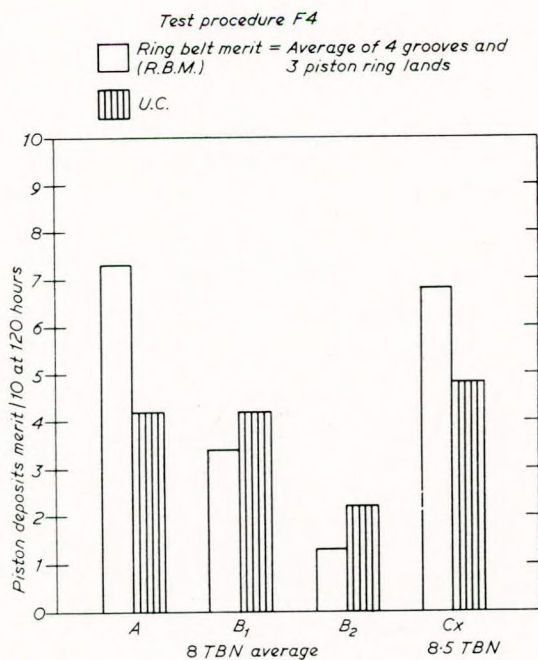


FIG. 16

## The Development of a Trunk Piston Diesel Engine Lubricant

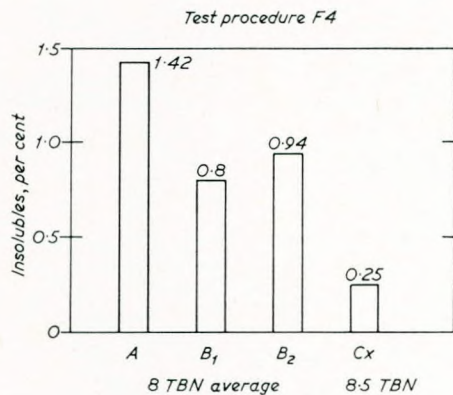


FIG. 17

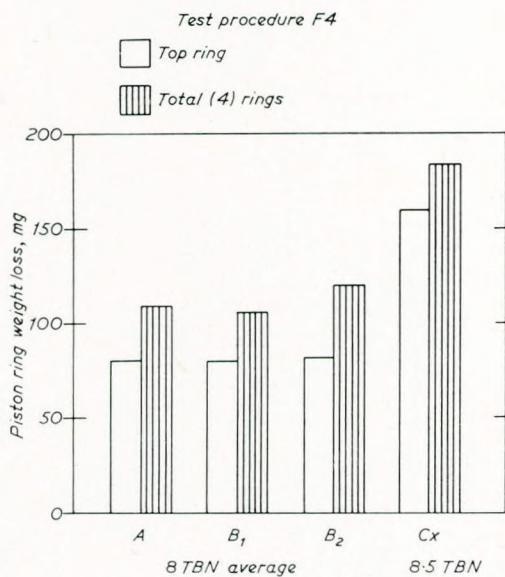


FIG. 18

**Materials:** Fuel: A mixture of residual and distillate to give a viscosity of 39.0 seconds Redwood No. 1. Sulphur content: 1.4 per cent. Lubricant: 13.6 kg.

**Conditions:** Run-in and test procedure as outlined in IP 231/69T.

**Test Duration:** 120h.

**Oil Make-up:** Adjust each 12h as IP 231/69T.

TABLE V—TEST PROCEDURE F.4 (ALKALINITY RETENTION)

Test Time	Alkalinity Retention as Percentage of Original			
	8 TBN Average			8.5 TBN
	A	B <sub>1</sub>	B <sub>2</sub>	Cx
Start	100	100	100	100
12	95.4	100	82.0	85.9
24	85.1	100	73.0	85.9
36	52.0	74.3	60.0	70.6
48	72.8	74.8	60.0	69.4
60	76.3	71.5	56.0	65.9
72	73.6	61.5	54.0	63.5
84	67.5	62.7	48.0	56.5
96	45.9	55.7	47.0	55.3
108	64.4	53.8	40.0	47.1
120	42.3	52.3	39.0	47.1

TABLE VI—TEST PROCEDURE F.4 (IRON CONTENT)

Test Time	Iron Content During Test ppm			
	8 TBN Average			8.5 TBN
	A	B <sub>1</sub>	B <sub>2</sub>	Cx
12	N.S.	13	36.5	31
24	18	18	33	32
36	13	21	20	37
48	17	24	24	37
60	18	28	26	37
72	27	24	29	37
84	41	28	20	43
96	N.S.	52	25	44
108	40	471	30	44
120	20	515	29	44

**Crankcase Charge:** 5 kg.

**Oil Samples:** Each 12h from oil adjustment. Samples examined for iron content. TBN (method E.4). Millipore filtration technique used to determine insolubles level.

**End of Test Examination:** Piston ring wear by weight loss. Piston deposits.

### Full Scale Engine Tests

Marine/Industrial commercial power unit availability in a laboratory is not normally encountered for lubricant evaluation. The laboratory owners (engine builders) are usually extensively involved in engine development work and therefore lubricant evaluation time is at a premium. Consequently comparative data on A, B, C, and Cx lubricant types are not available at this time.

The Cx lubricant in different TBN forms has been successfully evaluated.

### Mirrlees K Major

A three-cylinder engine under uprated conditions became available at the Stockport Works of Mirrlees Blackstone. Lubricant Cx (26 TBN) was used for some 600h and engine strip revealed:

- 1) 2 pistons—completely clean in ring land/groove area;
- 2) 1 piston—trace deposits in the second groove, remainder of the ring land area clean;
- 3) the piston cooling space (oil cooled) in all cases completely clean;
- 4) ring sticking non-existent;
- 5) turbo-charger case, blades, nozzle ring and shroud deposits "normal";
- 6) crankcase extremely clean;
- 7) filtration no problem;
- 8) piston ring and cylinder liner wear negligible;
- 9) oil consumption 1.01 g/kWh (0.75 g/bhph)—Alkalinity stabilized at 18 TBN.

### Pielstick 4PA6-280

This four-cylinder engine running at a higher speed than the K Major. 1050 rev/min/600 rev/min was used to evaluate a Cx lubricant at 31.5 TBN. Deposit control was assessed as excellent on examination of the pistons after a test of some 550h.

- 1) crankcase extremely clean;
- 2) piston ring and cylinder liner wear negligible.

A more detailed description of the K Major and PA6-280 tests can be found in reference (1).

### Ships Tests

Successful one year evaluation tests on the Cx lubricant have resulted in approval by SEMT-Pielstick of the use of an SAE 30 grade (30 TBN) in their PA6 and PC2 engines. A

## The Development of a Trunk Piston Diesel Engine Lubricant

similar approval has been granted by M.A.N. for the use of an SAE 40 grade (30 TBN) in their RV and VV 40/54 and 52/55 engines. Cx lubricants in the 20-25 TBN range in a variety of base stocks are being evaluated in vessels using Stork Werkspoor TM410, Pielstick PC2 and M.A.N. VV40/54 power units.

Comprehensive evaluation of Cx types and comparison with a type B lubricant over a three year period are sufficiently encouraging to warrant consideration of an extension to the period between examinations. The particular power unit involved consists of twin engines with separate lubricant systems. This arrangement allows the evaluation of two lubricants during the same period and the SEMT-Pielstick units lend themselves readily to spot checks on piston, valve, liner condition.

### Fuels used in Laboratory Engine Tests

	Gasoline	Gas oil	Residual fuel	
	A4	F1 "Run in"	(1) F4	(2) F1
Used in test procedure	A4	F1 "Run in"	F4	F1
Specific gravity	0.745	0.828	—	0.914
Sulphur per cent wt.	0.08	0.94	1.3	2.8
Oct rating (res.)	93	—	—	—
Oct rating (motor)	84	—	—	—
T.E.L. g/l.gal	3.66	—	—	—
Vapour pressure	8.4	—	—	—
Dist. I.B.P., °C	37	—	—	—
End. Pt., °C	187	—	—	—
Viscos., 37.7°C. cs	—	2.68	5.17	269
Carbon res. (Rams)	—	0.1	—	9.35
Carbon res. (Con)	—	—	2.0	—
Vanadium, ppm	—	—	13	87
Sodium, ppm	—	—	13	65

- 1) 80 per cent/20 per cent mixture of marine distillate and residuals.
- 2) Mixture of medium and heavy residual.

### CONCLUSIONS

The principle of the "balanced" marine TPEO is proved in that in all cases where direct comparison is possible, the Cx type lubricant is equal to or better than existing lubricants.

The programme of laboratory evaluation is successfully reflected in the excellent performance of the lubricants on shipboard.

Efforts must continue in test procedure and equipment development in order to match the conditions to which the lubricant is subjected in its natural environment.

For laboratory test repeatability a source of constant specification fuel is desirable.

The area of piston ring and liner wear requires more extensive investigation. There may be a case for a "Sibenaler" type test or development of the Abingdon B<sup>2</sup> engine should it be commercialized.

A better understanding of the effects of centrifugal purification can only result from a more detailed and prolonged investigation.

Closer consultation between engine builders, engine operators and the lubricant specialists must be encouraged.

### ACKNOWLEDGEMENTS

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