MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

WEARING RATE IN DIESEL ENGINES USING LOCAL FUELS

ELKOTB,M.M.*,KOUSSA,S.S.**,SALEM, H.*** and SAYED,A.S.****

ABSTRACT

In the present study, corrosive wear is investigated in cylinders of locomotive, vehicle, tank and stationery diesel engines. Investigation was carried out in the field and under controlled laboratory conditions. Local fuels of different sulphur content and lubricating oils having different total base number (TBN) were used. Wear was determined qualitatively by a scanning electron microscope and quantitatively by bore dial guages and lubricating oil analysis using atomic absorption spectroscopy. The results show that the range of local wear coefficients is considerably higher than the international range. Wear rates for chrome plated liners are much smaller than that of cast iron liners. Simple generalised relations for predicting the rate of wear as a function of oil TBN are proposed.

INTRODUCTION

The use of diesel engines is expanding rapidly in Egypt within both the military and civil sectors. For instance, the total installed Diesel power in the civil sector has increased by about 50% during the period from 1971 to 1981. This can be attributed to the well known merits of Diesel engines relative to the other types of prime movers.

It is rather redundant to hint the undesirable results of wear and its effects on the operation costs. The problem of wear in diesel engines, however, is aggrevated in Egypt by Certain local factors, notably the excessive sulphur content of the fuel and dust concentration in the atmosphere. The sulphur content of more than 60% of the total diesel fuel produced in 1980 exceeds 1% and is sometimes up to 4.5%. This leads to severe corrosive wear, presumably much more than the internationally acceptable limits.

Wear in engines is the subject of voluminous literature reporting mainly experimental investigations; theoretical studies exist albeit rare. Reference |3| provides a comprehensive and up-to-date overview of the subject.

* Professor, ** Assistant Professor, *** Lecturer, Mechanical Power Department, Faculty of Engineering, Cairo University, Giza, Egypt.
**** Graduate student, Military Technical College,Cairo, Egypt.

The effects of operating conditions, fuel and lubricant on wear in Diesel engines have been studied in the following references among others : Engine load |4-8| ; Engine speed |5-7 and 9| ; Coolant temperature |4, 5, 7, 10 and 11| ; Fuel sulphur content |4, 9 and 12| ; Lubricating oil alkalinity |8 and 13 - 16|.

All cited references agree that wear increases as load, coolant temperature above 65°C and/or fuel sulphur content increases. Contradicting statements, however, are reported regarding the effects of speed, coolant temperature below 65°C and lubricant TBN.

Information on wear in case of chrome plated liners has not been found. Considerable disagreements exist in case of chrome plated rings. The local ranges of variation and patterns are not covered in whole.

Data on wear coefficients of Diesel engines may be found in references |17 - 19|. It should be noted, however, that the figures reported in these references are determined under conditions different from the local ones. Hence, care should be excercised when conclusions are drawn from comparisons involving them.

The study of the wearing rate in cylinders and cylinder liners of diesel engines using local fuels is, therefore, of great interest. The present work undertakes such a study for various types of engines, namely locomotive, vehicle, tank and stationery engines.

The objective set for the work is to determine the wear coefficients under the local conditions and compare them with the corresponding international norms. This has been achieved by field and laboratory tests for various combinations among engines using :

- Cast iron and chrome plated liners.
- Fuels with various sulphur content.
- Lubricating oils with various fresh total base number (TBN).

It should be emphasized that generalised relations are not sought, and indeed do not exist. Any quantitative result is strictly applicable only in the conditions under which it has been determined. The results are, however, extremely useful for qualitative expectations.

EXPERIMENTAL SET UP

Investigation has been carried out on various diesel engines in four-stages to define the effect of power, number of cycles and cylinders, cylinder material and cooling system on wearing rate. Specifications of the tested engines are given in Appendix 1.

In the first stage, 236 cylinders has been inspected as follows: 109 cast iron liners from locomotives covered an average distance of 350,000 km; 39 cast iron cylinders from vehicles covered an average distance of 40,000 km and 88 cast iron liners from tanks covered an average distance of 5000 km. The wear pattern of these cylinders has been determined using dial bore gauges of readability 2 μm and error less than 3%.

In the second stage, specimens have been cut out from liners and piston rings, where severe wear has been visually detected, and were inspected by a scanning electron microscope of magnification up to 180000 times to define the type of wear. A magnification of 200 to 750 times has been found suitable for such inspection.

In the third stage, ten locomotives, running on the Aswan-Cairo route, have have been followed up to investigate lubricating oil degradation and wearing rate-Wear metals, such as iron, copper and chrome present in the lubricating oil were determined by analysing the used oil with an atomic absorption spectrophotometer with an error less than 5%. The total base number (TBN) of the used oil was determined by potentiometric acid titration according to ASTM D 664 and ASTM D 2896 with an error less than 2% while capillary tube viscometer was used to determine oil viscosity according to ASTM D 445 with an error less than 1%. Four of these locomotives were equipped with cast iron liners and the other six with chrome plated liners. The fuel used was of sulphur content 1.2% when determined by bomb method ASTM-D129 with an error 1.2%. Nine of these engines used lubricating oil "A" with initial TBN of 7.8 mg KOH/g. The tenth engine, which was equipped with chrome plated liners, used lubricating oil "B" with initial TBN of 13 mg KOH/g.

In the fourth stage, a laboratory test has been carried out on a stationery engine set up, the layout of which is shown in Fig.1. The test was done to investigate the effect of sulphur content on lubricating oil degradation and on engine corrosive wear. Two fuels have been investigated, gas oil and summer diesel of sulphur content 0.95 and 0.26% respectively. Two lubricating oils of TBN 11.7 and 6.0 were used in this test. Engine load, speed and coolent temperature and rate were kept constant during the test. Samples of the used oil had been withdrawn at various working hours and analysed for TBN, viscosity and wear metals using the above mentioned techniques.

RESULTS , ANALYSIS AND DISCUSSION

Wear in Cylinder Liners

The distribution of wear depth along the tested cylinders and cylinder liners on the thrust and thrust free sides has been measured at different locations. A sample of these measurements is shown in Fig.2 and more detailed results can be found in Ref.1 and 2. In order to assess the results of these wear measurements, the measured wear depth is compared with calculated wear depth using the following equation |19| :

$$h = KPD \qquad |1|$$

where h is the wear depth, K is the wear coefficient, P is the thrust between ring and liner and D is the sliding distance.

The calculated wear profile was determined for each type of engines based on full load average rated speed for locomotive 60 km/hr, army vehicles 40 km/hr and tanks 15 km/hr, average value of wear coefficient 0.92×10^{-10} mm^3/N |2| and the covered distance. The points of metal to metal contact where the film thickness is smaller than the lower limit for fluid film lubrication, were determined from oil film loci over a complete cycle |19|:

The calculated wear depth distribution is compared with the measured frequency distribution and the most probable wear depth in Fig.3. The loci of the extreme value of measured wear depth are also shown. The study of these results shows that there is excessive wear almost at all sections along the cylinder and 6% of cylinders show excessive wear resulting from ring stick. At section 2,46% of the liners show excessive wear in spite of high relative speed and oil viscosity caused by microseizure and adhesion due to inadequate lubrication. This is confirmed by the photographs taken by the scanning electron microscope for specimens at this section, photo 1 and 2. At section 3, 56% of liners show excessive wear inspite of high lubricating film thickness due to corrosion. Photo 3 confirms the presence of corrosion in specimens taken at this section. The excessive wear near the scavenging ports for locomotive engines is relatively high due to blow off of the lubricating oil film when the piston crown uncovers the scavenging ports. At sections 4-6, the calculated wear depth is zero and therefore the measured wear depth may be attributed to corrosion and microseizure as a result of the absence of hydrodynamic lubrication. The wear depth for vehicle engines is smaller than locomotive engines due to lower power/cylinder. However, high percentage of cylinders showed excessive wear resulting from short drive cycle , long idling periods, lower TBN of oil and high sulphur content of fuel. Tank engines showed more excessive wear due to high temperature resulting from low tank speed and dusty atmosphere caused by sand exitation by tank crawler. The hard sand particles promotes abrasion process.

Total Wear Metals

The measurements of metal concentration against working distances are important to evaluate the total wear rate and oil degradation as these metals catalyse the oil oxidation process and affect deposit formation. The concentration of Fe,Cu and Cr metals as shown in Figs.4 for locomotive engines is well below EMD standard limits after a satisfactory working distance of 270000 km. It is clear from these results that the iron wear in CI liners is about 28% higher than in chrome plated liners at the end of the first 100000 km when using oil with alkalinity 7,8 and becomes greater than the EMD limit for both liner before the end of the second oil change. The copper wear for both liners is well below the EMD limit with Chrome plated liners showing more copper wear in the first working distance and equality is retained after the first oil change. Comparison of iron wear for different engines under different operating conditions as shown in Fig. 5 and 6 shows that it is strongly dependent on engine type, oil alkalinity and sulphur content of fuel. As regards locomotive engines and stationery engines, the wear metal in ppm (W_{metal}) as a function of oil TBN for TBN ranges between 3 and 13 is given in Table 1 : Thus a general relation between engine wear for Fe,Cu and Cr and oil TBN can be proposed in the following form

$$W = x\, e^{y(TBN)}$$

where the values of the parameters x and y depend on the cylinder liner material and lubricating oil |2|. Moreover, the wear coefficient was calculated based on the average wear rate of each cylinder and the results are given in Fig.7. The results show that the wear coefficient under local condition is higher than the international values due to high dust concentration in the atmosphere.

6

Table 1. Relation between wear Metal and TBN

Engine type	Fuel sulphur content	Type of oil	Cylinder liner material: C.I.	Cylinder liner material: Cr - plated
Locomotive	1.2%	A	$W_{Fe}=1737\ e^{-0.8043(TBN)}$	$W_{Fe}=663\ e^{-0.7801(TBN)}$ $W_{cr}=149\ e^{-0.6933(TBN)}$
		B	--	$W_{Fe}=202\ e^{-0.3969(TBN)}$ $W_{cr}=217\ e^{-0.49(TBN)}$
Stationery	0.95%	B	$W_{Fe}=326\ e^{-0.3997(TBN)}$	--

CONCLUSIONS

The results of the present work leads to the following conclusions.

1. The ranges of most probable wear coefficients have been determined for different engine types. They acccount for different variables and can facilitate wear prediction under local enviromental conditions. The results show that the local average wear coefficientsare 1.45×10^{-10} to 3.92×10^{-10} mm^3/N which is higher by 1.5 to 5.5 times than the international value.

2. Simple equations are proposed to predict the amount of diesel engine wear metals as a function of oil TBN. These equations are aplicable under local operating conditions and TBN in the range 3 to 13 mg KOH/g.

3. Using chrome plated liners and oils of high TBN reduces wearing rate considerably. On the other hand, with oil of TBN 6 the wear increases by 10% for every 0.1% increase in the sulphur content of fuel.

4. Direct and indirect iron wear measurements show that the average value ranges from 2 to 6 mg-Fe/hp/10^3km. The cylinder iron wear contributes by about 37 to 57% of this value.

5. The frequency of oil change has a considerable effect on oil drain period. Six to thirty two percentage reduction in the period of oil change is obtained for the second and third oil change relative to the initial oil change period.

REFERENCES

1. Farag,S.A.,Elkotb, M.M., Koussa, S.S., EL-Sherbeeny, M.G., Salem,H., Youssef, H. and Abd-Elmaboud, S.S. "Wear Pattern in Egyptian Railway Locomotive Engines" Research Project First Annual Report, Faculty of Engineering, Cairo University (1982).

2. Abd-Elmaboud, S.S. "A Study of Wear in Diesel Engines" M.Sc. Thesis, Faculty of Engineering, Cairo University (1983).

3. Peterson, M.B. and Winer, W.O. (Eds.) "Wear Control Handbook" ASME, New York, U.S.A. (1980).

4. Pinotti, P.L., Hull, D.E. and Mclaughlin, E.J. "Application of Radioactive Tracers to Improvement of Automotive Fuels, Lubricants and Engines" SAE Transactions, Vol.3 (1949).

5. Robbins, B.A., Pinotti, P.L. and Jones, D.R. "The Use of Radioactive Tracer Techniques to determine the Effect of Operating Variables on Engine Wear" SAE Preprint No.72U (1959).

6. Martin, J.J. and Williams, H.A. "The Effect of Engine Design Variables upon Compression Ring Wear as determined by Radioactive Tracer Technique" SAE Paper No.362 B (1961).

7. Bolis, D.A., Johnson, J.H. and Daavetilla, D.A. "The Effect of Oil and Coolant Temperature on Diesel Engine Wear" SAE Paper No.770086 (1977).

8. Michael, M.I. "Performance of Multigrade Oils in Tractor Diesel Engines" The Fourth Int. Seminar on Developments in Fuels, Lubricants, Additives and Energy Conservation, Cairo (1983).

9. Ellis, J.C. and Edgar, J.A. "Wear Prevention by Alkaline Lubricating Oils" SAE Transactions, Vol.61, pp.244-251 (1953).

10. Nutt, H.V., Landen, E.W. and Edgar, J.A. "The Effect of Surface Temperature on the Wear of Diesel Engine Cylinders and Piston Rings" SAE Preprint No. 340 (1954).

11. Popovich, M. and Peterson, R.W. "The Effect of Fuel Sulphur and Jacket Temperature on Piston Ring Wear as determined by Radioactive Tracer" Oregon State College, Bulletin No.33 (1953).

12. Moore, C.C. and Kent, W.L. "Effect of Nitrogen and Sulphur Content of Fuels on Diesel Engine Wear" SAE Transactions, Vol.1, No.4, pp.687-693 (1947).

13. Giddings, G.N- and Barett, S.I. "Base Numbers by the Aceto-Perchloric Acid Method" J. of Inst.of Petroleum, Vol.57, No.553 (1971).

14. Stytz, W.E. "Corrosive Ring Wear" Discussion, SAE Paper No.67039 (1967).

15. Pike, W-C., Pywe, R.E. and Tudtson, S.G. "Wear Phenomena of Chromium Plated Rings as revealed by Radioactive Tracers" SAE Paper No.690773, (1969).

16. Cook, B.A. "The Effect of Diesel Lubricant Detergent Additives on Piston Ring Wear" J. of Inst. of Petroleum, Vol.55, No.544 (1969).

17. Neale, M.J. "The Problems of Piston Ring and Cylinder Scuffing in Internal Combustion Engines" Ministry of Technology, BR 21433, U.K. (1970).

18. Sreenath, A.V. and Venkatesh, S. "Experimental Studies on the Wear of Engine Components" Wear J., Vol.16, p. 245 (1970).

19. Ting, L.L. "Lubricated Piston Rings and Cylinder Bore Wear" Wear Control Handbook, ASME, New York, pp.609-665, (1980).

6

Appendix 1

Main Specifications of Test Engines

Service	Locomotive	Vehicle	Tank	Stationery
Make	Henschel	Deutz	USSR	Usha
Model	2-stroke, water-cooled	4-stroke, air-cooled	4-stroke wat.cooled	4-stroke water cool-ed
Type	EMD - 64^5 E3	F/A 6L 614	Y - 54	520
Number of cylinders	12	6	12	1
Arrangement of cylinders	V-45°	V-90°	V-60°	Vertical
Bore, ...mm	230	100	150	87.5
Stroke, ...mm	254	140	180/186.7	110
Rating output....hp	2475	84	520	5.2
Rating speed,....rpm	900	1800	2000	1500
Compression ratio	14.5	17.8	14/15	
Displacement/Cylinder,.lit	10.57	1.33	0.324	
Conn,rod/crank radius ratio	4.6/1	4/1	4/1	

Appendix 2

Analysis of Fresh Lubricating Oils A and B

Property		Test method	Oil A	Oil B
K.viscosity at	40°C,CSt	ASTM D.445	169	160
	100°C,CSt	ASTM D.445	15.4	15.2
TBN,	mg KOH/g	ASTM D-2896	7.8	13
		ASTM D-664		11.7
Total Contamination :		Atomic Absorption		
	Iron, ppm		3	2
	Cu, ppm		2	2
	Cr, ppm		-	-
	Si, ppm		-	-
Additive,	%wt.		11.4	14.3
Viscosity index			86	93

6

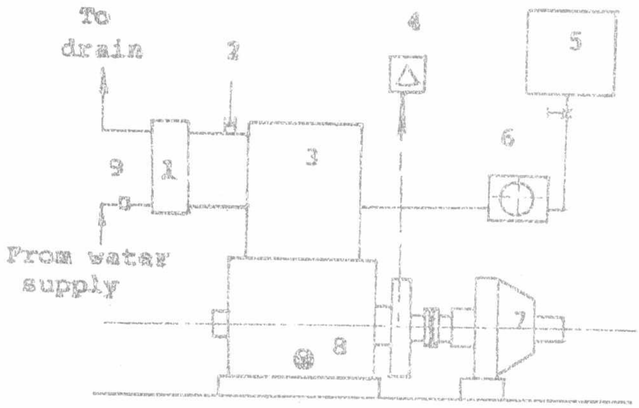


Fig.1 Scheme of the experimental set-up

1-Cooling tower
2-Outlet coolant thermometer
3-Engine assembly
4-Speedometer
5-Fuel tank
6-Fuel flow meter
7-Dynamometer
8-Oil drain valve
9-Temperature controller.

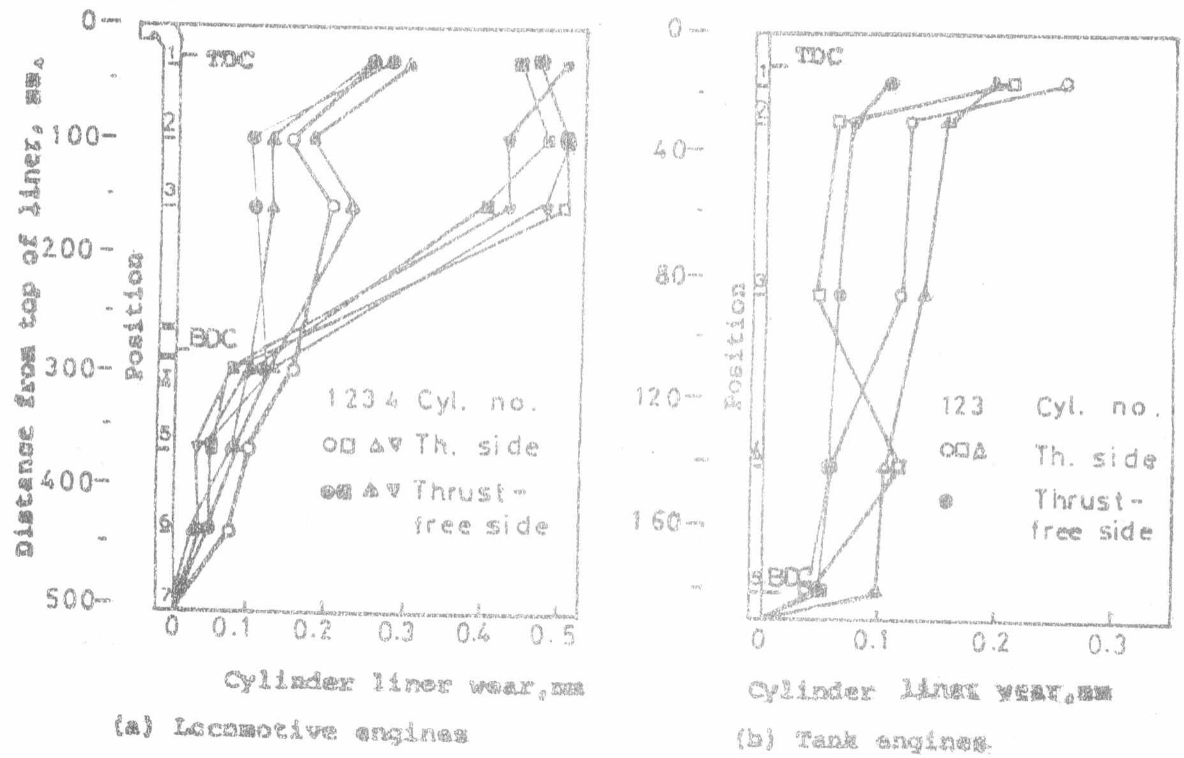
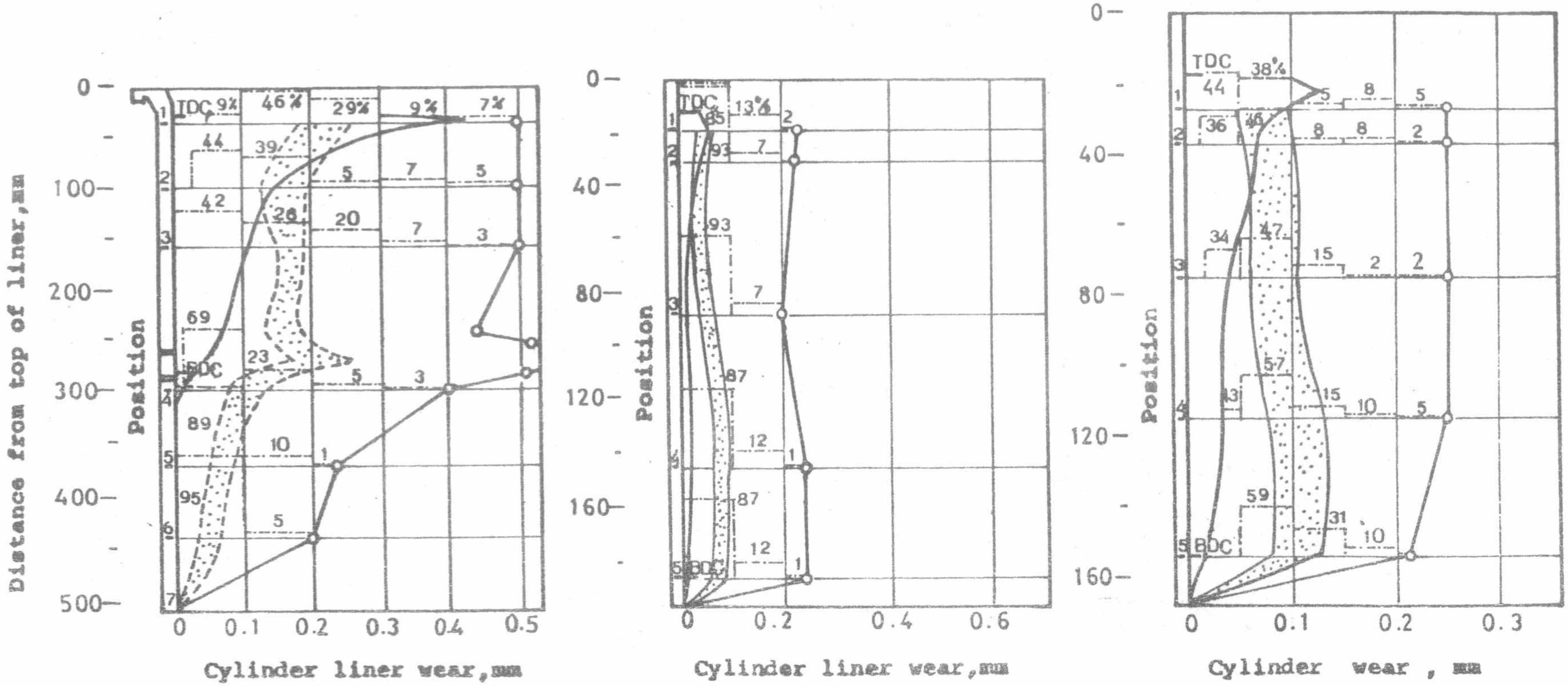


Fig. 2 Distribution of wear depth along the tested cylinders.



(a) Locomotive engines (b) Tank engines (c) Vehicle engines.

Fig.3 Wear distribution on the thrust side (perpendicular to crankshaft axis) of tested cylinders.

—— Calculated
-·-·- Measured frequency distribution of wear
▒ Range of most probable value of measured wear
-o-o- Loci of extreme wear values.

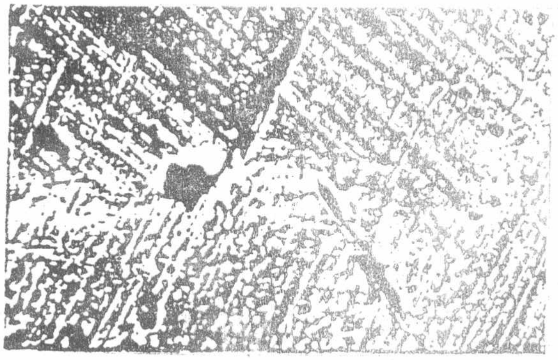


Photo 1.

(a) Corrosion and abrasion of piston ring 330X.

(b) Microseizure of cylinder liner 200X.

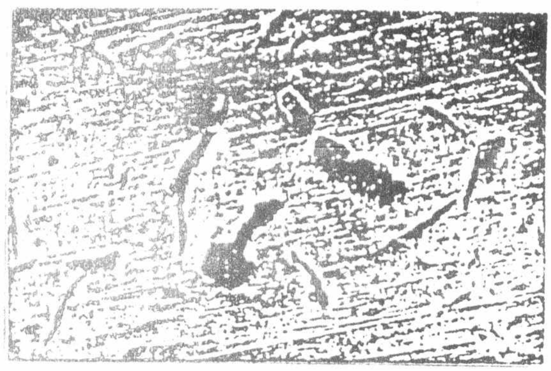


Photo 2.

(a) Adhesion of piston ring 650X.

(b) Microseizure and adhesion of cylinder liner 200X.

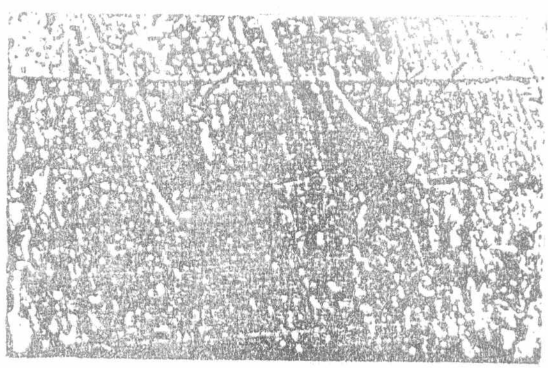


Photo 3. Corrosion of cylinder liner 200X.

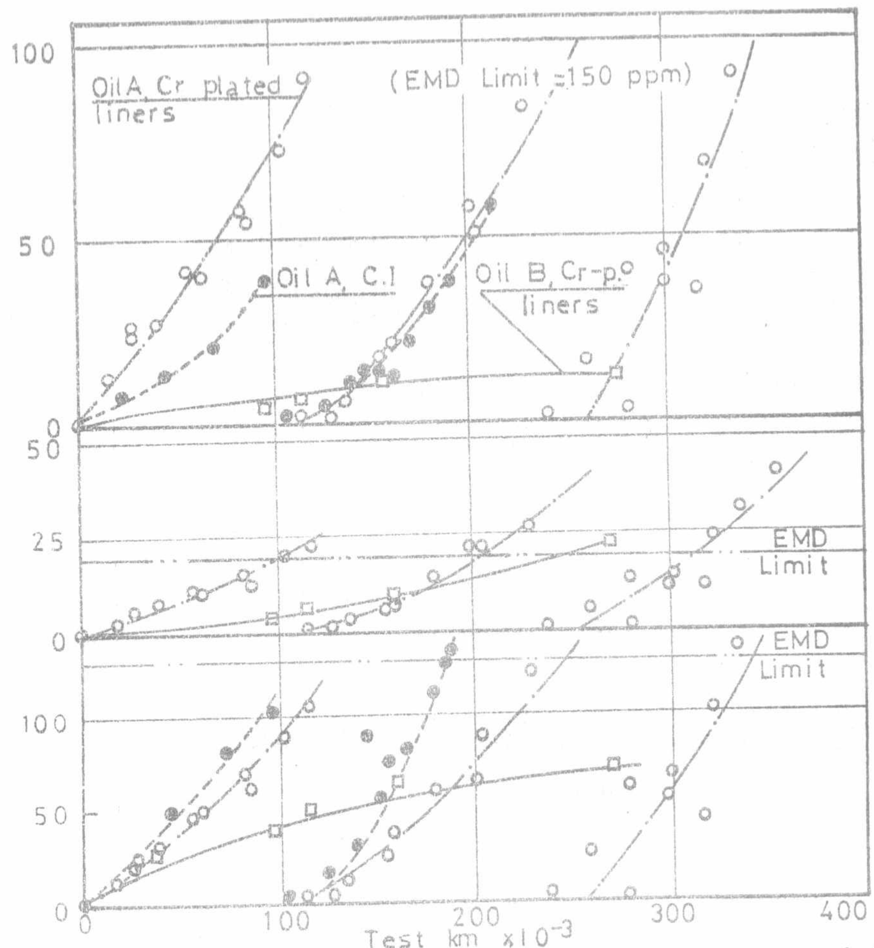


Fig.4 Effect of oil type and cylinder liner material on wear metals of locomotive engines.

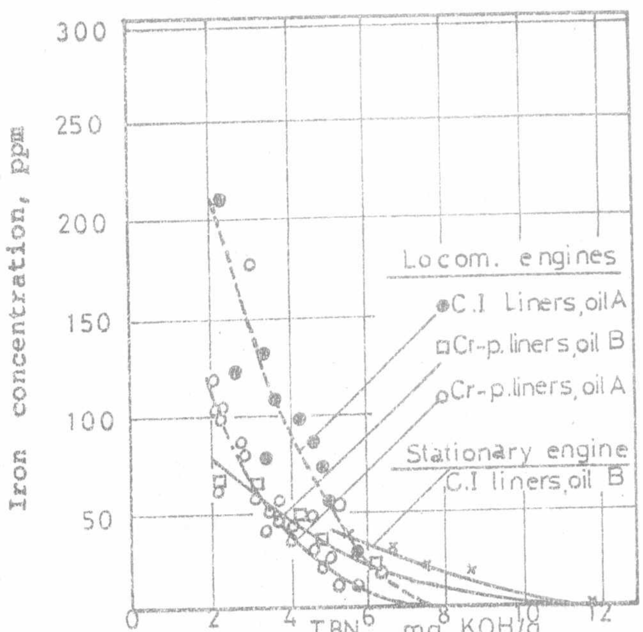


Fig.5 The relation between TBN and iron wear in locomotive and stationary engines.

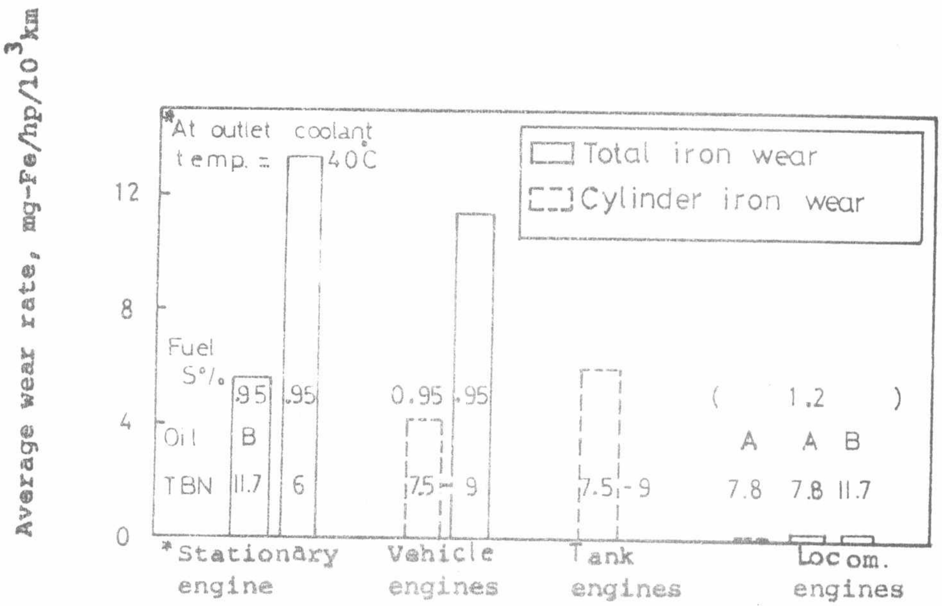


Fig.6 Comparison between the average wear rates for the test engines.

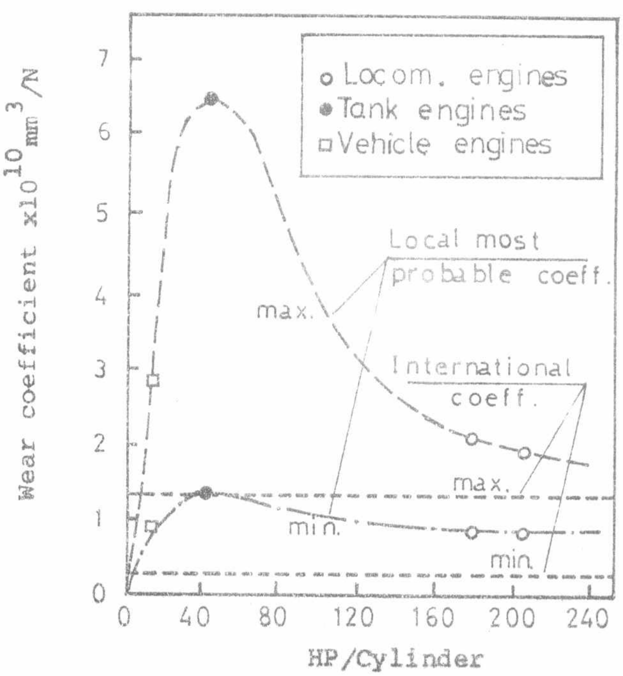


Fig.7 Comparison between the international and the trend of most probable local wear coefficients.