Cylinder Oil Drain & Engine Performance Analysis

Condition Monitoring and Maintenance Planning for 2-stroke marine diesel engines

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The Authors

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ABSTRACT

This paper presents the case for comparing cylinder lubricant drain analysis and engine performance data from 2- Stroke Marine Diesel Engines in order to monitor and optimize engine performance and operation. The procedure has been developed by the authors over the past five years and requires that the cylinder drain oil samples and fuel samples are collected simultaneously with the recording of engine performance data.

It has been noted that the characteristics of the fuel in use and the engine operating conditions are reflected in the drain oil analysis. Conversely this means that information from the cylinder drain oil can provide an insight into the engine conditions and confirm whether these are normal or otherwise. Cylinder Drain & Engine Performance analysis procedures detect abnormal combustion or lubrication conditions providing early warning of developing problems whether from incorrect settings or component malfunction.

INTRODUCTION

The use of cylinder drain analysis to evaluate the performance of cylinder lubricants is a procedure familiar to the major oil companies for more than 40 years. In 1994 the authors’ company reversed the procedure and began using drain analysis to investigate combustion and lubrication conditions in engines. The first conclusion of this testing in 1996 was that many modern large bore 2-stroke engines were being over-lubricated and that the deposits from the burning of excess lubricant were causing ring seizure and liner wear. In recent years the engine manufacturers have revised their lubrication recommendations and now propose cylinder lubricant feed rates ranging 30% to 50% below previous recommendations.

The diagnostic procedures for studying fuel characteristics, cylinder lubricant drain analyses and engine performance have been developed over the past three years and are now applied to over 150 ships. Sampling of fuel and cylinder drain oil and collection of engine performance data is carried out between 4 and 12 times per year, the frequency being dependent on the voyage schedule and operator requirements.

By interpretation of the information collected developing faults can be identified well before they may be visible through the performance data or physical inspection. Evaluation of information from the analysis also allows recommendations for adjustments to fuel, lubrication and engine settings, and for planning of overhaul of injectors and cylinder units, including when overhaul intervals can be extended. The service is used to plan overhaul by need, rather than according to engine hours, and to assist Chief Engineers and Engineer Superintendents to ensure economic and reliable engine operation.

Engine Performance is normally recorded when the ship is in loaded condition, at engine load of 80% to 90% of Maximum Continuous Rating and in calm sea. These same conditions are also required for sampling of cylinder lubricant drain oil.

By taking the cylinder lubricant drain samples and sample of the fuel from the fuel pump at the same time as the recording of engine performance, a unique snapshot is taken which enables precise comparisons to be made. For an accurate evaluation a full range of engine data is required, most, or all of which is normally collected by engine room staff when recording performance data. The introduction of digital diesel analysis has simplified data collection. And the provision of additional information, such as Injection angles, Ignition angles and Mean Indicated Pressure (MIP) facilitates more precise diagnosis.

Engine Performance Diagnosis

It is important that performance data is carefully studied and evaluated to ensure reliable and economic operation of the engines. However many companies leave the responsibility of evaluation of Performance Data to the superintendents and chief engineers to interpret and act on the data. This is a duty which is becoming more difficult as superintendents are over-loaded with work and travel, and the number of engineers on board ship is reduced. Engine Performance Analysis requires painstaking study to arrive at an accurate evaluation of engine operating conditions and recommendations for action.

Cylinder Lubricant Drain & Engine Performance Analysis

In the paper *"Study of the Relationship between Cylinder Lubricant Drain condition and Performance Parameters of 2-stroke Cross-head Engines"* the case was made for the analysis of Cylinder Lubricant Drain oil as a method for the determination of engine operating conditions, the planning of engine maintenance and setting of cylinder lubricant feed rate.

Over the past two years cylinder oil drain and fuel analyses and engine performance data have been collected from 150 ships, and procedures developed for scrutinizing and interpreting approximately 500 pieces of information which are used to develop each ship report. This paper reports on the progress made since 2001 in the use of Cylinder Lubricant Drain & Engine Performance Analysis as an important tool for obtaining a more complete understanding of operating conditions in 2-stroke marine diesel engines and for planning of engine maintenance.

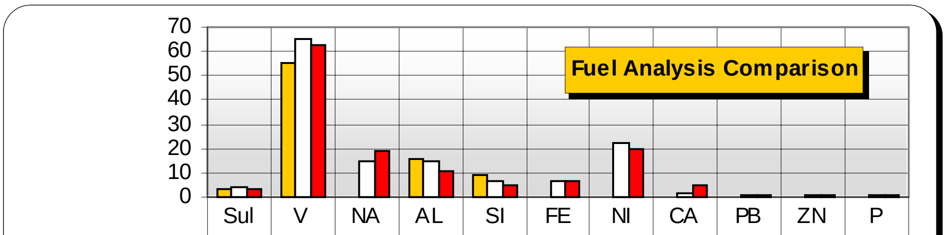
Sources of Data

To be able to develop a complete diagnosis of engine operating conditions a range of data is required which includes:

- Analysis of the fuel delivered
- Analysis of the fuel before high pressure fuel pump
- Engine performance data, including fuel and lubricator settings
- Archive from the Diesel Analyzer (if fitted).
- Overhaul and Cylinder calibrations data.
- Analysis of a cylinder drain oil sample from each cylinder unit

The Fuel

The characteristics of fuel vary between deliveries, due to changes in the crude source and/ or fuel source, variations in refining procedure and differing blend components, and contaminants. Once on board the fuel is treated by settling, centrifuging, heating and filtration before it is injected into the combustion chamber. The fuel injected therefore differs from the fuel delivered. - See **Fig 1**



	Sul	V	NA	AL	SI	FE	NI	CA	PB	ZN	P
Bunkers	3.63	55		16	9						
Before Purifier	3.78	65	15	15	7	7	22	2	1	1	1
ME Rail	3.7	63	19	11	5	7	20	5	1	1	1

Figure 1 - Comparison of Bunker Delivery Analysis with Analyses at Purifier and Fuel Pump

The Engine

The ability of the fuel to burn completely in the time available and produce energy to drive the engine is dependent not only on the physical properties of the fuel but also on the design characteristics, the engine settings and maintenance condition of the engine.

The Lubricant

Cylinder lubricant is injected into each cylinder to provide a uniform film of lubricant on the liner wall. The main purposes of the lubricant are to ensure the basic functions of lubricating the piston and liner, and sealing the gap between piston ring, piston and liner wall. The additive package in the cylinder lubricant maintains the stability of the lubricant, neutralizes acid condensation on the liner wall and scavenges fuel and lubricant debris. - See **Fig 2**

The condition of the lubricant changes as it proceeds from the point of injection until the drain. The change in the characteristics of the lubricant reflects the conditions of combustion and lubrication in each cylinder. **-** See **Table 1**

Analysis of the lubricant drain oil is considered by many operators as adequate to show whether the engine is over-, or under-lubricated, and this service is being offered by some lubricant suppliers. It is however insufficient to rely only on measurement of the alkaline reserve and iron content of the drain oil. A reliable interpretation depends on taking into account the characteristics of the fuel in use, the maintenance condition of the engine and performance data.

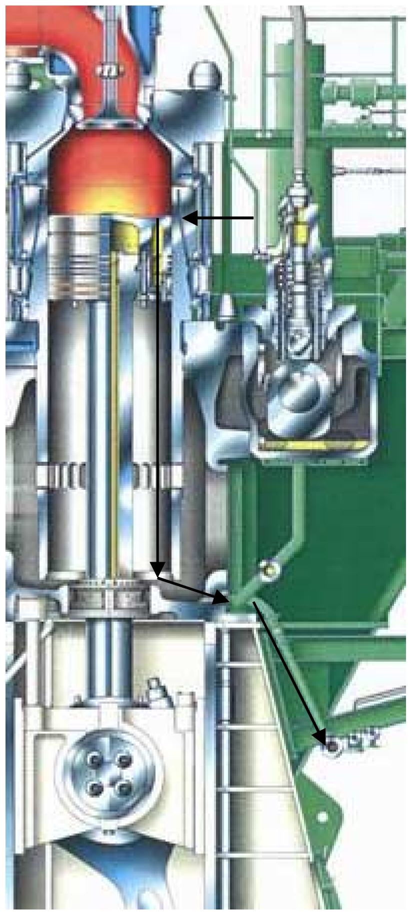


Figure 2 - Diesel Cylinder cut-away showing point of lubricant injection and lubricant drain.

Cylinder No:	1	2	3	4	5	6	New Oil
PHYSICAL PROPERTIES							
Viscosity	30.89	29.66	28.97	26.01	25.38	30.50	**17.25**
Water	0.95	1.00	0.90	0.90	0.95	1.00	**0.05**
TBN	**28.7**	**11.6**	**16.7**	**23.8**	**28.2**	**15.0**	**68.43**
Sooty Insol.	0.2	0.3	0.3	0.3	0.3	0.3	**0.1**
Dispersancy	72	70	68	70	71	68	**95**
SPECTROCHEMICAL ANALYSIS							
Iron	107	**250**	173	160	154	**265**	**4**
Lead	0	0	0	0	0	0	**0**
Copper	10	25	19	18	27	20	**0**
Chromium	5	6	5	3	5	7	**0**
Aluminium	25	28	30	24	27	28	**0**
Nickel	35	68	47	40	45	38	**0**
Silver	0	0	0	0	0	0	**0**
Tin	15	24	16	14	17	20	**0**
Silicon	24	36	26	24	22	25	**7**
Boron	0	0	0	0	0	0	**0**
Sodium	25	34	26	24	23	23	**7**
Phosphorous	14	28	11	11	12	11	**14**
Zinc	22	31	25	26	23	21	**5**
Calcium	23,920	20,330	21,350	23,660	24,050	22,880	**25,710**
Barium	0	0	0	0	0	0	**0**
Magnesium	72	92	65	73	57	53	**39**
Titanium	0	0	0	0	0	0	**0**
Molybdenum	0	0	0	0	0	0	**0**
Vanadium	116	265	120	97	84	103	**0**

Table 1 - Typical Analysis of Cylinder Lubricant Drain Oil

Collection of Fuel, Cylinder Drain & Engine Performance Data

A sample of fuel is taken before the high pressure fuel pumps and one sample of cylinder drain oil from each cylinder is taken from the drain line off the diaphragm. Simultaneously engine performance is recorded and, when available, a set of digital analyzer data is also recorded.

Conclusions can be drawn concerning the combustion, lubrication and operating conditions in each cylinder of an engine by collating and comparing the following information:

- analysis of the fuel injected
- analysis of cylinder lubricant drain oil
- engine pressures and temperatures
- angles of injection, ignition and Pmax
- profile of indicator diagram pressure curves
- fuel rack and VIT settings
- scavenge system temperatures and pressures
- cylinder lubricator settings
- cylinder calibration and engine maintenance records

Study and comparison of the analysis data establishes the conditions of combustion, lubrication and engine operation in respect of the specific time frame of about one hour whilst the samples and performance is collected.

Diagnosis of Engine Performance

Analysis of the fuel as delivered, fuel before purifiers and fuel before the high pressure pumps quantifies:

- the elements that can affect combustion and wear.
- effectiveness of purification and filtration

Analysis of the lubricant drain oil sample shows:

1. Contamination by water
2. Presence of fuel or fuel ash
3. Amount of lubricant ash
4. Leakage of system oil into the under-piston space
5. Wear debris from metal components
6. Reserve Alkalinity to prevent corrosive wear
7. Reserve Dispersancy to maintain piston cleanliness

1. Contamination by water

Water will enter the engine with the scavenge air or by leakage. The amount of water in the drain oil will be a function of:

- Ambient Relative Humidity and Temperature
- Efficiency of air cooling, separation and drainage
- Engine load
- Water ingress from leaking coolers, from cracks in liners, cylinder covers or mountings. - See **Fig 3**

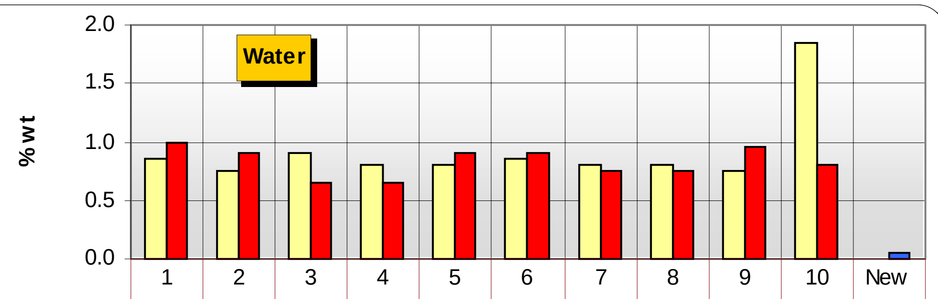
The amount of water in the drain oil sample compared with the ambient conditions and engine load can therefore be related to the condition of the water separator or fouling of the air-cooler and prompt a recommendation for cleaning. Or the water may point to a blocked water separator drain or leakage from cracked liner/cylinder mountings.

2. Presence of fuel or fuel ash

The normal metallic ashes found in residual marine fuels are vanadium and nickel. The efficiency of atomisation and combustion conditions influence the amount of vanadium and nickel ash in the drain oil, thus allowing evaluation of combustion conditions:

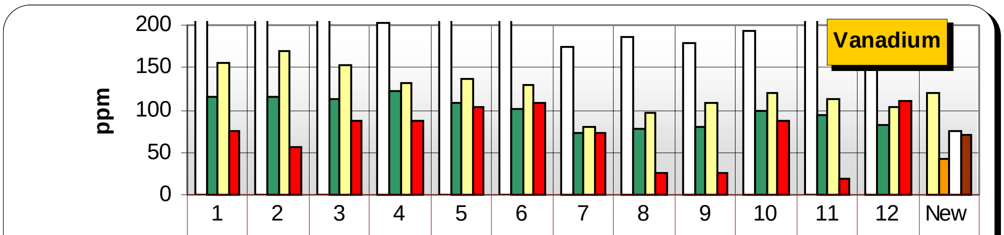
- Efficiency of atomization, which is affected by the degree of fuel contamination.- See **Fig 4 & Pic 1**
- Cylinder pressures (Pmax, Pmax – Pcom and MIP), which influence the quantity of fuel ash. - See **Fig 5**
- Efficiency of the piston ring to liner wall seal, which influences both fuel and fuel ash

Although the presence of Iron is well recognized as an indicator of liner wear, Iron content is noted to vary relative to Pmax and Pmax-Pcom, whereby small pressure changes are replicated by changes in Iron content of the cylinder drain oil.



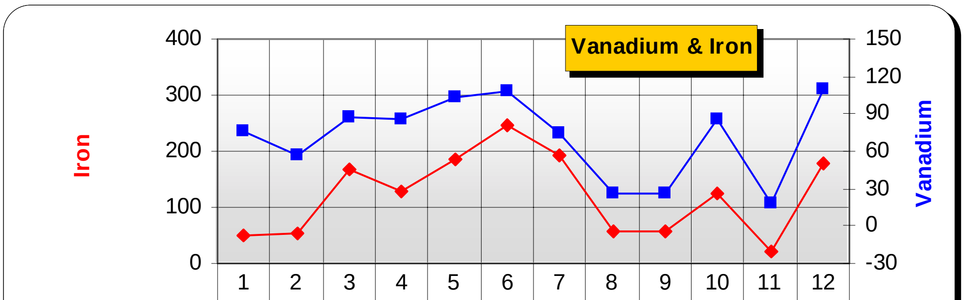
	1	2	3	4	5	6	7	8	9	10	New
6th May 2002	0.85	0.75	0.90	0.80	0.80	0.85	0.80	0.80	0.75	1.85	
26th July 02	1.00	0.90	0.65	0.65	0.90	0.90	0.75	0.75	0.95	0.80	0.05

Figure 3 – Evidence of water ingress from crack in liner detected before affecting engine performance

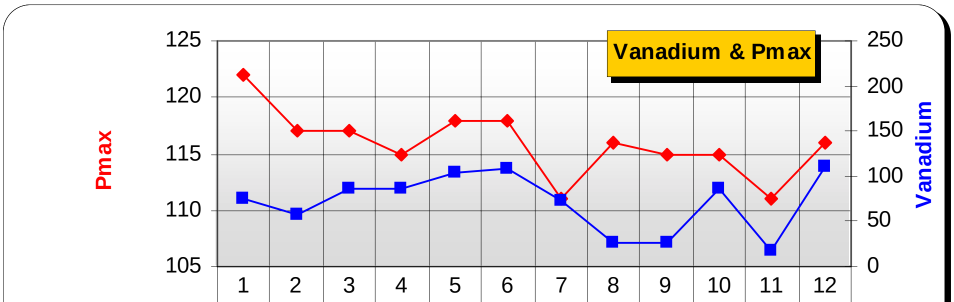


	1	2	3	4	5	6	7	8	9	10	11	12	New
10th Mar 02	322	305	226	202	219	218	173	186	180	192	211	184	120
28th May 02	116	115	114	123	109	102	74	77	80	98	93	83	43
19th Aug 02	155	170	152	131	137	130	81	97	109	119	112	103	75
4th Dec 02	76	57	87	86	104	109	74	27	27	86	18	110	70

Figure 4 - The Vanadium content in the drain oil varies according to Vanadium content in the fuel.

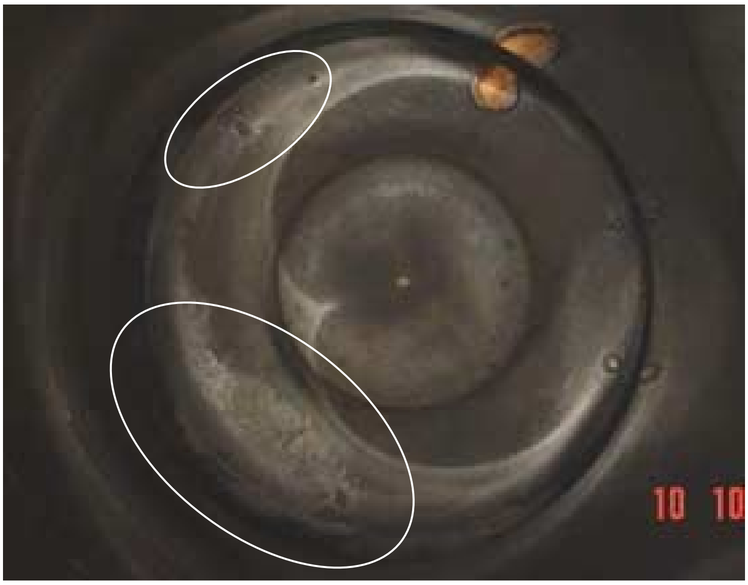


	1	2	3	4	5	6	7	8	9	10	11	12
Iron	49	55	168	130	184	245	192	56	56	125	22	179
Vanadium	76	57	87	86	104	109	74	27	27	86	18	110

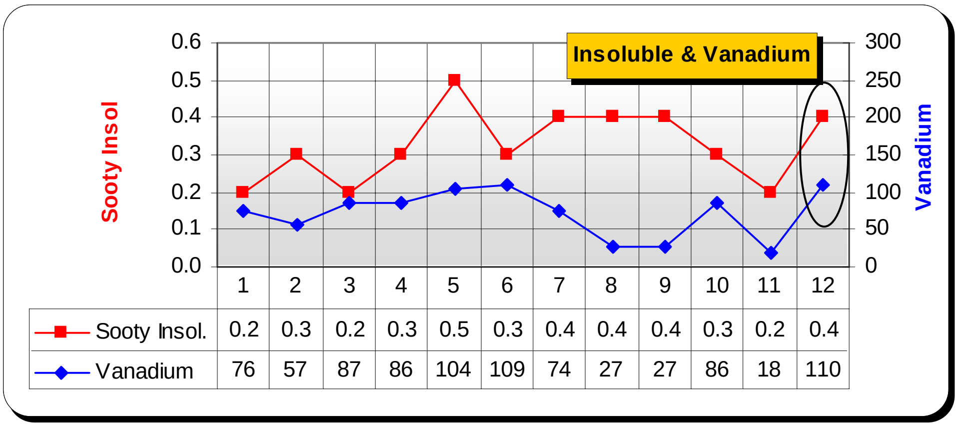


	1	2	3	4	5	6	7	8	9	10	11	12
Pmax	122	117	117	115	118	118	111	116	115	115	111	116
Vanadium	76	57	87	86	104	109	74	27	27	86	18	110

Figure 5 - High Vanadium corresponds with high Pmax and high Iron – Faulty injectors Units 5, 6, 10 & 12



Picture 1 – Faulty Injectors on Unit 10 corresponding to high Vanadium and Iron in Fig 5.



	1	2	3	4	5	6	7	8	9	10	11	12
Sooty Insol.	0.2	0.3	0.2	0.3	0.5	0.3	0.4	0.4	0.4	0.3	0.2	0.4
Vanadium	76	57	87	86	104	109	74	27	27	86	18	110

Figure 6 - High Insolubles with High Vanadium indicate blow-by in Unit 12.

The degree of fuel and fuel ash contamination therefore provides a method of evaluating the status of fuel injection condition and how that is influenced by the maintenance condition of fuel pumps, injectors, VIT system and settings.

The degree of fuel contamination of the drain sample is one of the indicators of ring seizure and blow-by. Early detection and prompt action to rectify faulty conditions can prevent development of serious damage and ensure efficient operation. **-** See **Fig 6**

Other Ash present in the fuel can come from the refining process, aluminium/ silicon catalytic fines, or waste lubricants and are seen to influence lubrication and combustion conditions. **-** See **Fig 7**

3. Amount of lubricant ash

Burning of cylinder lubricant in the combustion chamber will cause an increase in lubricant ash which can be due to:

- Excess lubrication
- Late combustion – see **Fig 8**

High lubricant ash is a factor to be considered when recommending adjustment to lubricant feed rate. It may also prompt an investigation into the injection timing, efficiency of atomisation or fuel combustibility characteristics.

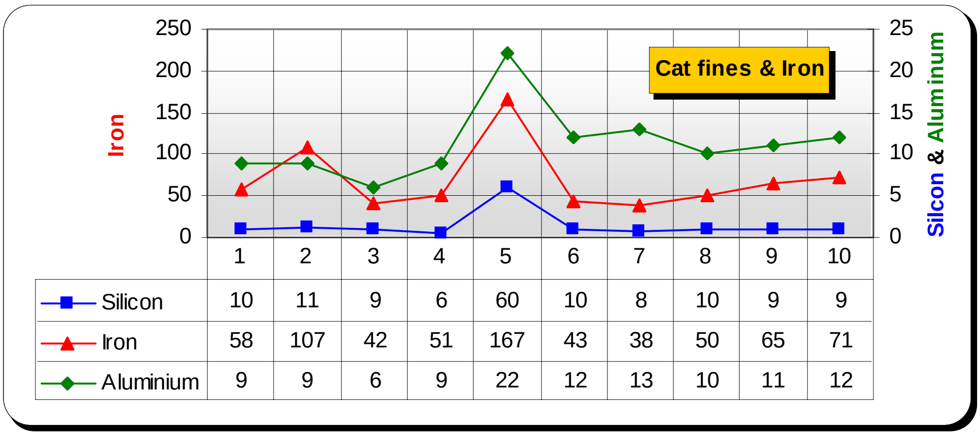


Figure 7- High Aluminium and high Silicon in Unit 5 is causing wear as indicated by high Iron.

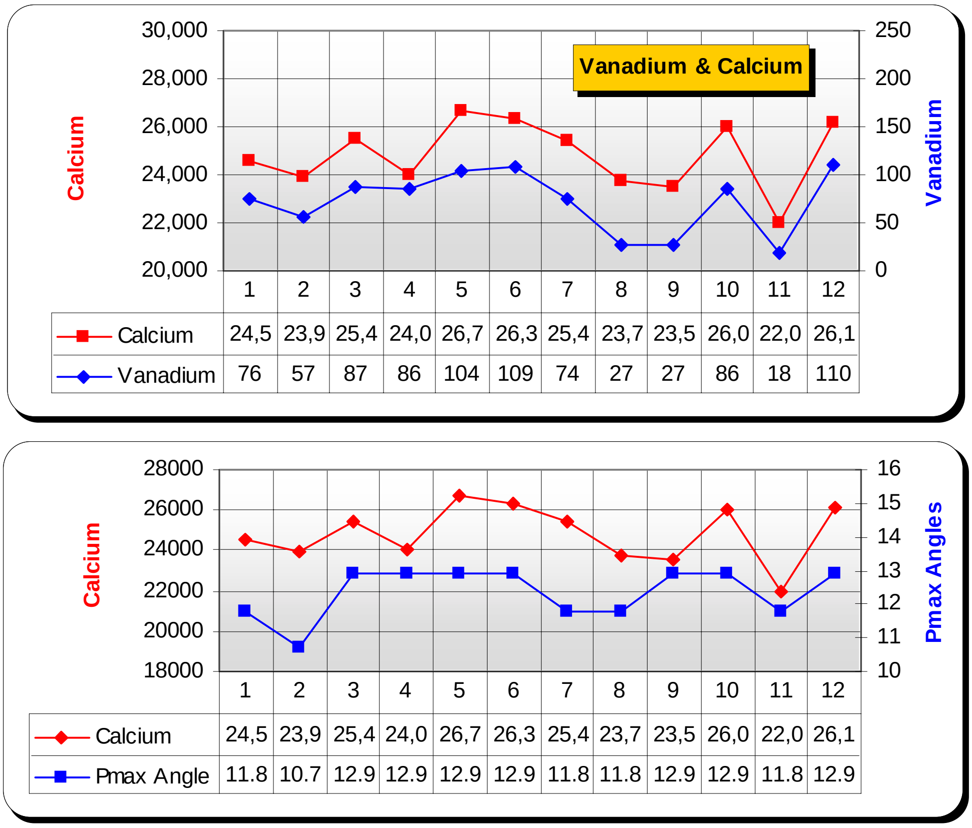


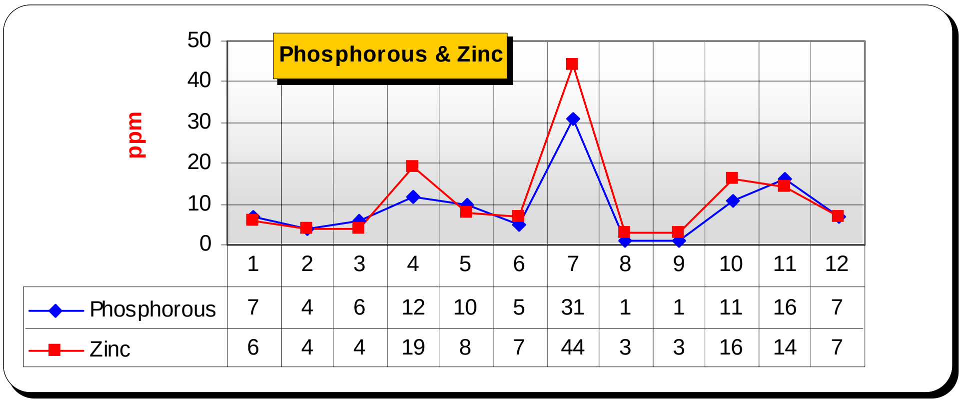
Figure 8 - Late and unstable combustion is causing burning of the cylinder lubricant in Units 5, 6, 7, 10 & 12

4. Leakage of system oil into the under-piston space

The presence of system oil in the cylinder lubricant drain is identified in the drain oil analysis which provides pointers to:

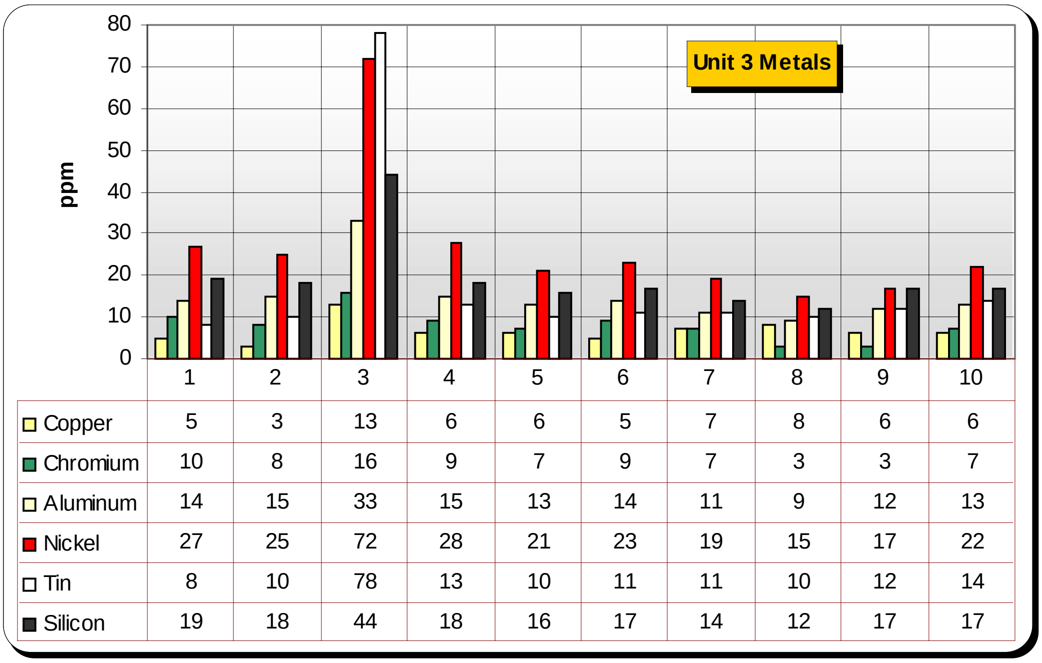
- Identification of leaking piston rod stuffing boxes – see **Fig. 9**
- Degree of loss of system oil into the under-piston space

System oil leaks up through the piston rod stuffing box entering the under-piston space and mixing with the cylinder drain oil. This will dilute the drain samples masking the true values in the analysis and needs to be taken into account when interpreting the analysis results. Identification of system oil contamination may prompt a recommendation for overhaul of the piston rod stuffing box.



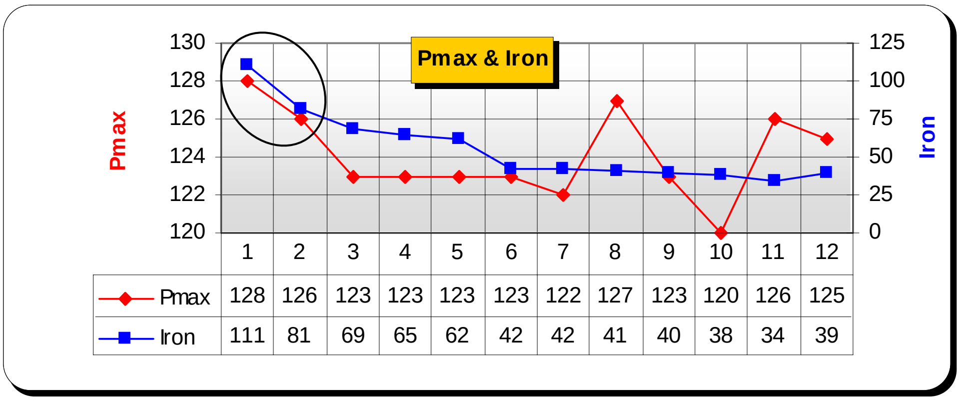
	1	2	3	4	5	6	7	8	9	10	11	12
Phosphorous	7	4	6	12	10	5	31	1	1	11	16	7
Zinc	6	4	4	19	8	7	44	3	3	16	14	7

Figure 9 - System oil is leaking into Unit 7



	1	2	3	4	5	6	7	8	9	10
Copper	5	3	13	6	6	5	7	8	6	6
Chromium	10	8	16	9	7	9	7	3	3	7
Aluminum	14	15	33	15	13	14	11	9	12	13
Nickel	27	25	72	28	21	23	19	15	17	22
Tin	8	10	78	13	10	11	11	10	12	14
Silicon	19	18	44	18	16	17	14	12	17	17

Figure 10 - Abrasion between piston skirt and liner wall in Unit 3



	1	2	3	4	5	6	7	8	9	10	11	12
Pmax	128	126	123	123	123	123	122	127	123	120	126	125
Iron	111	81	69	65	62	42	42	41	40	38	34	39

Figure 11 - High Pmax in Units 1 and 2 is influencing wear as indicated by high Iron

5. Wear debris of different metals

Wear debris from steel, copper, aluminium, tin, chromium is found in the cylinder drain oil identifying components which are wearing. Analysis of the metals provides information about:

- Degree of wear of rings and liners, piston ring grooves and piston skirt – see **Fig 10**
- Condition of combustion.
- Influence of cylinder pressures on ring or liner wear – see **Fig 11**
- The presence of piston deposits causing abrasion

6. Reserve Alkalinity

Alkalinity of the cylinder drain oil is mainly influenced by the sulphur content of the fuel, quantity of fuel injected, lubricant feed rate, cylinder wall temperature and Pmax. Other influences are system oil and fuel oil contamination. A study of the reserve alkalinity provides information on:

- Ability of the lubricant to prevent corrosive wear
- Influence of variations in Pmax between cylinders – see **Fig 12**
- Degree of contamination by fuel and system oil
- Adequacy of the lubricant feed rate

7. Reserve Dispersancy

The Dispersancy of the lubricant is dependent on the degree of contamination by fuel and lubricant debris and influences the efficiency of the cylinder lubricant to maintain piston cleanliness. Dispersancy is therefore able to indicate:

- Unstable combustion and incomplete combustion – see **Fig 13**
- Late completion of combustion.

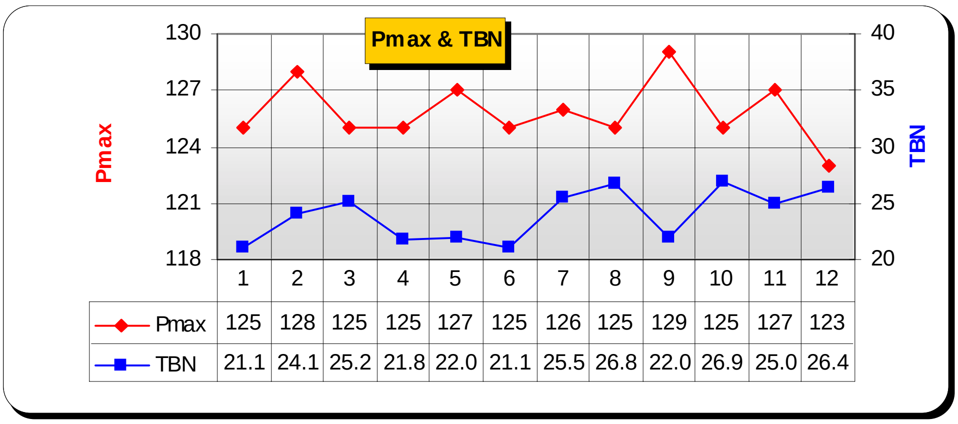


Fig 12 - Units with higher Pmax have lower TBN due to increased acid condensation.

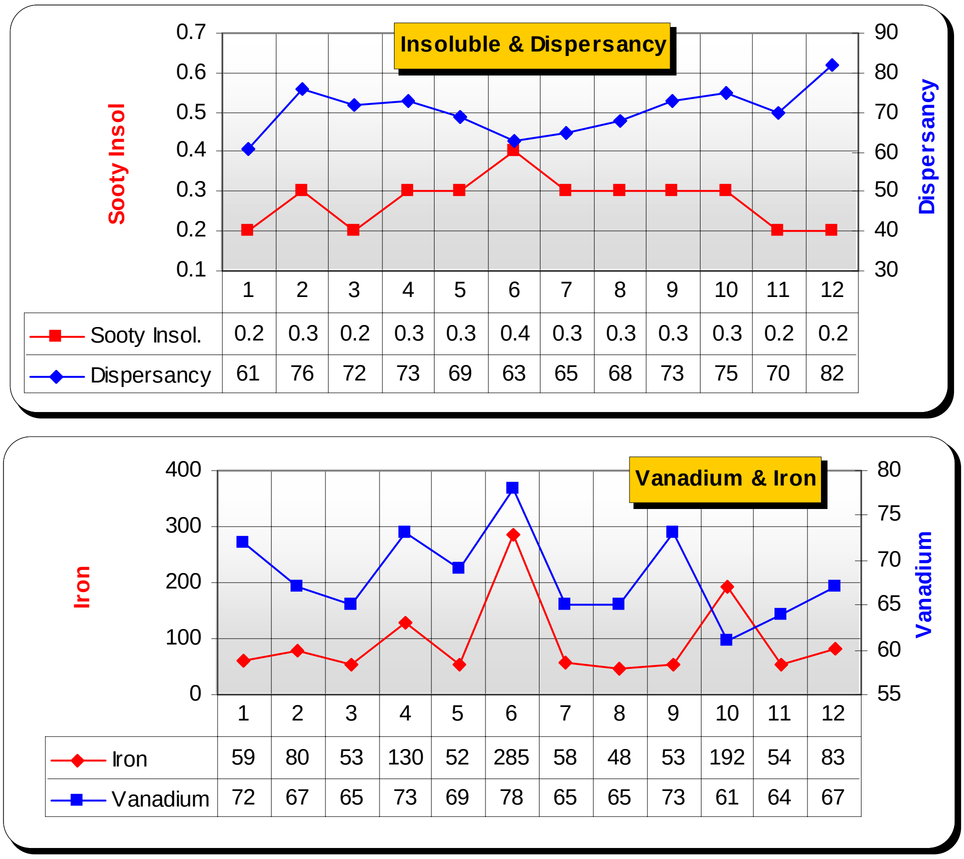


Figure 13 - Low Dispersancy resulting from poor combustion corresponds with high wear on Unit 6

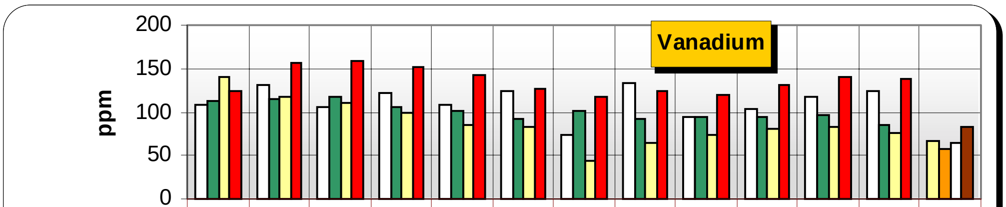
Engine Performance Data

It is important that performance data is carefully studied and evaluated to ensure reliable and economic operation of the engines. Many companies, especially the larger ones, have Marine Diesel Engine Performance Engineers to monitor and analyse the mass of data collected from Performance measurements in the fleet. They provide support and advise the Superintendents and Chief Engineers on action to be taken to ensure reliable and economic operation of the engines.

However not all companies have dedicated Performance Engineers. The superintendents and chiefs carry out the interpretation themselves and instigate instructions for action. This duty is becoming more difficult as superintendents are over-loaded with work and travel, and the number of engineers on board ship is reduced.

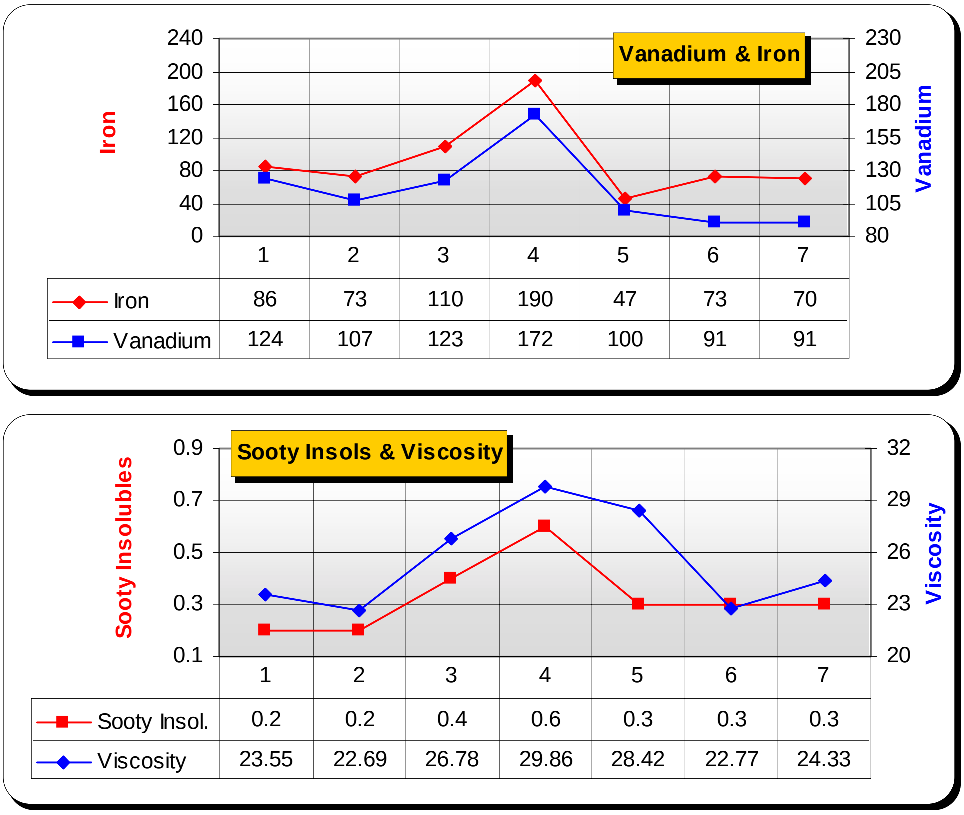
Engine Performance Analysis requires painstaking study to arrive at an accurate evaluation of engine operating conditions. And conventional monitoring of temperatures and pressures allows detection of malfunction and abnormalities only when the conditions have developed to a significant stage which can be too late.

Combining the data derived from fuel and cylinder drain oil analysis with the performance data allows deteriorating conditions to be detected in the early stages of development before it can be picked up by conventional means. This not only speeds up the evaluation, but allows a more accurate and timely detection of deteriorating conditions. Early detection and timely corrective action can avoid costly damage.



	1	2	3	4	5	6	7	8	9	10	11	12	New
1st Sept 02	108	131	105	122	109	123	73	134	94	103	118	125	67
24th Oct 02	113	114	117	105	102	93	102	92	95	95	96	85	58
23rd Dec 02	141	117	111	99	86	83	43	64	73	81	82	77	65
5th Feb 03	124	156	159	152	142	126	117	123	119	131	141	137	82

Figure 14 - Low injection temperature results in incomplete combustion.



	1	2	3	4	5	6	7
Iron	86	73	110	190	47	73	70
Vanadium	124	107	123	172	100	91	91

	1	2	3	4	5	6	7
Sooty Insol.	0.2	0.2	0.4	0.6	0.3	0.3	0.3
Viscosity	23.55	22.69	26.78	29.86	28.42	22.77	24.33

Figure 15 - Evidence of blow-by past the ring pack of Piston No. 4

A Cylinder Drain and Engine Performance analysis provides a range of conclusions covering:

1. Adequacy of Fuel temperature at the injector – see **Fig 14**
2. Evaluation of efficiency of fuel atomization
3. Indications of fuel impingement
4. Quality of combustion, and completeness and delay of completion
5. Assessment of performance of Air-Coolers, Turbo-Chargers and Scavenge temperatures and pressures and their influence on engine performance.
6. Presence and effect of water on lubrication and wear
7. Adequacy of lubrication
8. Assessment of the degree and type of wear – corrosive or abrasive

9. Condition of piston rings and evidence of blow-by – see **Figs 15, 16, Pic 2**
10. Cleanliness of the piston
11. Abrasion of the piston skirt on the liner wall
12. Tightness of Exhaust Valves seats
13. Degree of system oil leakage past the piston rod stuffing boxes into the under-piston space.
14. Evaluation of Fuel Rack and VIT settings, and Injection/ Ignition/ Pmax timing
15. Interpretation of Indicator Diagrams and assessment of the balance of power between cylinder units.
16. Evaluation of cylinder compression and maximum pressures and exhaust temperatures.
17. Prioritisation of engine maintenance

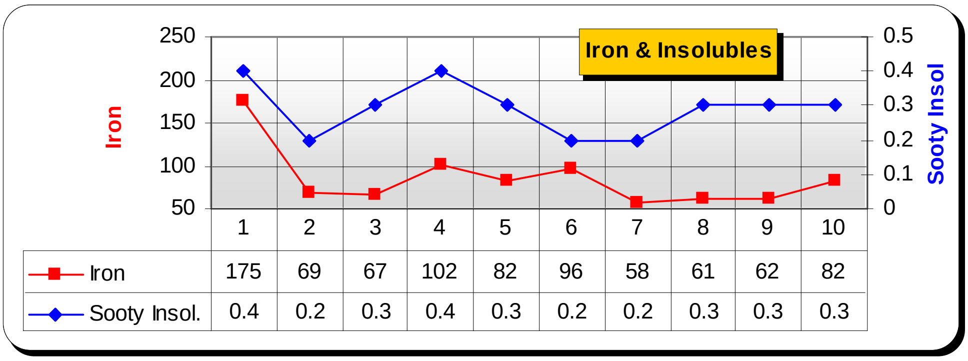


Figure 16 - At 2,157 hrs, analysis of Unit 1indicates blow-by and increased wear.

Picture 2 – Condition Unit 1 Fig 16 traced to excessive ring groove clearance and broken 1st ring.

Engine Maintenance

The data derived from fuel analysis, scavenge air parameters and cylinder drain oil interpretation provide a precisely detailed evaluation of the conditions of combustion and lubrication in each of the engine cylinders, confirming those which are functioning correctly, and highlighting others which require attention. The study will also identify reasons for any malfunction and signal the possible remedy. The chief engineer is therefore able to plan maintenance by need and focus attention on the units not performing normally.

Scavenge port inspection of pistons is strongly advocated by the engine builders for assessing the need for Unit overhaul. However evaluation of drain oil can identify incipient problems well before they can be identified by visual inspection, and may prompt a recommendation for adjustment of the maintenance schedule of certain components, such as injectors, even when a study of engine performance and a scavenge port inspection fails to indicate the need for maintenance.

Conversely, a unit due for overhaul in terms of operating hours may be postponed if drain analysis and performance confirm that it is performing well.

By early identification of changes in combustion and lubrication conditions in individual cylinders, the cylinder drain analysis is able to identify when a minor change in the spray pattern from an injector is beginning to cause an increase in wear, and signal an alert to plan the overhaul of the injector. Similarly development of ring failure can be identified at an early stage, weeks before it may become apparent from the performance data. Equally the data can confirm satisfactory conditions allowing extension of overhaul.

Conclusion

The combination of the analysis of fuel (as injected in the engine), cylinder lubricant drain oil, and Engine Performance is a powerful and precise tool for evaluating performance of 2-stroke cross-head engines.

The information derived allows:

- Engine settings to be adjusted to provide reliable and economic operation
- Engine maintenance to be planned according to need
- Early warning of faulty and abnormal operating conditions
- Comparison of engine performance of individual ships over time and across groups of ships
- Evaluation of the skills and training requirements of engine room personnel.

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