ANALYSIS OF MARINE DIESEL ENGINE CYLINDER LUBRICANT DRAINS AS A MEANS OF MONITORING ENGINE PERFORMANCE

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Mr. Terence McGeary began his marine engineering career in 1952 as a Shell Engineer Cadet. In 1964 he was appointed Technical Manager Industrial Lubricants for Total in East Africa, followed by appointment as Technical Manager Marine Fuels and Lubricants with Chevron for Europe and Scandinavia. In 1971 he joined Flame Shipping & Trading, owners of a small fleet of ships, and in 1973 he lead Flame into investigations in the use of fuel additives to reduce acid condensation on the liner wall of diesel engines. In 1982 he formed a partnership with Bycosin AB to develop the applications of fuel additives in marine diesel engines. His investigations into marine diesel engine combustion and lubrication conditions continue to the present date under the auspices of Flame Marine, which is providing a condition monitoring service to international ship operators.

Fabian Chew started his sea career as a cadet with Neptune Orient Lines in 1980 and took his first command as chief engineer in 1989. By early 1990, he was appointed as Technical Superintendent taking care of a fleet of large container vessels. In December 1996, he left NOL to start a company providing technical and management services to shipping companies. By mid 1997, the company started to provide technical service carrying out trials and inspections of ships. In March 1998 he was appointed Regional Manager (Far East) & Technical Consultant for Bycosin Marine and now has a similar position with Flame Marine.

Abstract

The authors have studied the condition of diesel engine cylinder lubricant drains over a number of years on modern long stroke large bore engines. This paper presents their findings and demonstrates how regular CLO drain analysis can be used to monitor combustion and lubrication conditions, provide alert of ingress of water and efficiency of the sealing of the piston rod glands, optimise lubricant consumption and plan the life of the diesel engine cylinder liner.

The cross-head diesel engine relies on the injection of cylinder lubricant through the liner wall to lubricate the piston. Ideally, the cylinder oil is injected between the 1st and 2nd piston rings when the piston is approaching the top of its stroke, and, after performing its duties, drains away to waste. This waste oil can provide useful information, concerning both lubrication and combustion conditions.

In practice, a large part of the lubricant injected is wholly, or partly, burned. Some of the burned lubricant remains as deposits on the liner wall and on the piston, and some exhausts with the combustion gases (depositing in turbo-chargers and economisers). The lubricant which finally finds its way to the under-piston scavenge space is laden with acid sludge, lubricant ash, partly burned heavy ends of fuel, fuel ash, wear particles and water.

Study of the changes, which have taken place to the cylinder lubricant and study of the contaminants in the lubricant, provides an insight into the engine operating conditions.

INTRODUCTION

For many years the marine lubricant suppliers have offered the operators of medium speed trunk engines a lubricant analysis service to ensure correct lubrication and operation of the engine. The characteristics of the lubricating oil change during engine operation and useful information can be found by analysing the lubricant on a regular basis.

The information gathered is useful to control depletion of alkalinity (TBN), the amount of contaminants, the degree of degradation of the lubricating oil, combustion conditions, and to signal the need to replace the lubricant.

The two-stroke crosshead marine diesel engine however has two separate lubrication systems, “once through” lubrication of the piston and cylinder liner, and a second for the crankcase. Analysis of the crankcase system oil is a service provided by most lubricant suppliers.

This paper considers the information which can be gathered from the analysis of samples of cylinder lubricant drain oil, the trends which can be seen when tabulating the analyses over a period of time, and the use which can be made of the information to improve the conditions and economics of operation of the 2-stroke crosshead diesel engine.

Diesel Cylinder lubricant

The cylinder lubricant is a blend of paraffinic base lubricating oils and an additive package. The components of the additive package provide alkalinity, dispersancy, detergency and, in some cases, anti-wear properties.

The functions of the lubricant are to:

- minimise the wear between the bearing surface of the piston rings and the cylinder liner
- provide a gas seal between the rings and piston ring grooves, and between the rings and the liner
- neutralise the acid which condenses on the liner wall and in the ring grooves
- transport away debris to the drain, being:
  - the fuel ash and incompletely burned heavy ends of the fuel,
  - the neutralised lubricant and the burned, and partly burned, lubricant and lubricant ash
  - the wear debris and particulate, such as sand, from the atmosphere

Marine Fuels

Most 2-stroke crosshead marine diesel engines are designed to burn the residue of the petroleum refining process. Over the years the demand for automotive and aviation fuels has increased resulting in the introduction of secondary refining to extract more light products from the residue. From a situation in the 1970's when residue represented 35% of the crude petroleum barrel, there are many refineries today delivering only 7% of the crude as residue.

The Vis-broken residue is very viscous and the more severely treated residues need to be blended with a cutter stock at 400^0C to enable it to be stored and handled within the refinery.

The selection of cutter stock influences the stability and the ignition quality of the residual fuel blends, such that the cutter stocks which maintain the stability of the fuel may have poor ignition and combustion characteristics. The deterioration in fuel quality, which has taken place over recent years, can have a marked effect on the ability of the cylinder lubricant to perform its functions.

For example, excessive ignition delay and late completion of combustion may cause the cylinder lubricant to be burned on the liner wall and can result in “dry” liner conditions with consequent piston fouling with lubricant ash, severe wear and scuffing.

Developments in Cross-head Engines

Ship operators have demanded continuous development of marine diesel engines to get more power per cylinder, and, whilst the temperatures and pressures have increased to produce that power, they have also ensured earlier ignition and complete combustion of the lower quality of marine fuel.

However most ship managers operate their engines at 85% to 95% of Maximum Continuous Rating, experience having indicated that operating at MCR frequently requires increased maintenance.

At lower engine loads, and hence lower combustion temperatures, combustion is frequently incomplete particularly when burning high asphaltene fuels. The incompletely burned heavy ends of fuel remaining in the engine will be picked up by the cylinder lubricating oil and can be observed when analysing the cylinder lubricant drains.

The authors’ observation, from analysis of hundreds of cylinder lubricant drain samples over a period of 6 years, indicates that acid condensation in fact increases with the higher engine operating loads in modern engines. It appears that the volume of acid, which condenses at higher engine loads, could be a restriction on further development of the power per cylinder.

CYLINDER LUBRICANT DRAIN SAMPLING

Cylinder lubricant is fed into the cylinder typically at rates in the range of 0.65g to 1.2g per bhp every hour. The authors have on occasion noted rates as high as 1.8g/bhp.hour. Assuming a single cylinder develops 2,000 bhp then the consumption of lubricating oil at a rate of 1g per bhp is 2kg per hour.

The lubricating oil is injected through quills in the liner wall and spreads over the liner surface to provide a lubrication film to lubricate the piston rings and the liner wall. The alkaline component of the lubricating oil film on the surface of the liner neutralises acid, which condenses out of the combustion gases onto the liner wall, leaving behind a neutral sludge.

The lubricant film is exposed to the high temperature combustion gases and is partly burned, remaining as ash or deposits in the engine, or is carried away by the exhaust gases. The balance of the cylinder lubricant pumps its way through the piston ring pack picking up combustion and lubricant debris and wear debris thus performing its duty of maintaining piston cleanliness. Finally the waste lubricant drips from the bottom rim of the cylinder liner onto the piston rod diaphragm, and is piped to a drain tank.

Engine designs differ in respect of the way the drain lubricant is finally led away, but most piston rod diaphragms are configured to allow the drain oil from each cylinder to run into a pipe and then into a manifold, which carries the lubricant to the used oil drain tank. Provision of a shut-off valve on the drain line from each cylinder unit and a sampling cock above the shut off valve can allow collection and sampling of the drain oil.

To obtain representative samples of the drain oil at any one time requires that the under-piston space and diaphragm surface be cleaned before taking samples.

The sampling procedure used by the authors has been that drain samples are taken every 30 to 45 days from each cylinder unit. This means that the under-piston space is cleaned in port before the samples are due to be taken.

Laboratory Analyses

At the time of taking a set of CLO samples engine operating parameters are entered on a standard form together with information about the fuel in use, and the ship delivers the samples to the ship's agent for forwarding by courier to the designated analytical laboratory.

The individual cylinder drain samples are analysed, results tabulated and interpreted, and forwarded to the shipping company within 5 to 10 days of the samples being received at the laboratory. To establish trends, the results of all previous analyses are plotted with the current values on a graph.

This paper examines the results obtained from analysis of cylinder lubricant drain samples taken from several large bore long stroke cross-head engines managed by ship operators in Europe, the Middle East and Asia-Pacific areas who use the Cylinder Lubricant Analysis service provided by the Authors' company.

CYLINDER LUBRICANT DRAIN ANALYSIS AND INTERPRETATION

By way of introduction to CLO drain analysis Table I shows two sets of values obtained from new cylinder lubricant and used cylinder lubricant.

PHYSICAL PROPERTIES		
	NEW OIL	**USED OIL**
Viscosity cst@100C	19.86	26.27
Water %wt	0.05	0.9
TBN mg/KOH/g	68.7	41.1
Sooty Insolubles %wt	0.1	0.7
Dispersancy %	95	50
SPECTROGRAPHIC ANALYSIS units ppm		
Iron	5	60
Lead	0	14
Copper	0	125
Chromium	0	0
Aluminum	0	10
Nickel	0	10
Silver	0	0
Tin	0	13
Silicon	25	28
Sodium	26	29
Phosphorous	9	15
Zinc	7	19
Calcium	23700	21060
Barium	0	0
Magnesium	53	57
Titanium	0	0
Molybdenum	0	0
Vanadium	0	56

Table I: Comparison of analyses between new and used cylinder lubricant

Study of the changes to the lubrication oil and the degree of those changes can provide valuable information about:

- Combustion condition
- Adequacy of lubrication
- Acid condensation as influenced by sulphur content in the fuel, engine loading, and degree of jacket cooling
- Wear conditions
- Variations in fuel quality
- Efficiency of water separation and water leakages.
- Performance of piston rod glands
- Performance of fuel additives

Combustion Conditions in the Diesel Cylinder

Changes in combustion conditions in the diesel engine cylinder affect the cylinder lubricant and can be detected by analysis of the cylinder lubricant drain oil.

Table II shows how poor atomisation or blow-by affects the cylinder lubricant.

PHYSICAL PROPERTIES						
Unit No	**1**	**2**	**3**	**4**	**5**	**6**
Viscosity cst@100C	25.34	22.76	22.83	22.82	20.33	19.96
Water %wt	0.85	0.85	0.9	0.9	0.9	0.85
TBN mg/KOH/g	35.1	40.8	42.6	48.9	48.8	49.4
Sooty Insolubles %wt	0.5	0.5	0.4	0.2	0.4	0.2
Dispersancy %	**65**	**68**	73	89	**59**	72
SPECTROGRAPHIC ANALYSIS units ppm						
Iron	156	165	102	33	88	44
Lead	6	8	4	9	6	7
Copper	51	64	65	59	31	33
Chromium	0	0	0	0	0	0
Aluminium	20	15	16	12	15	10
Nickel	38	18	23	8	17	6
Silver	0	0	0	0	0	0
Tin	0	2	0	0	0	0
Silicon	17	12	12	7	11	10
Boron	0	0	0	0	0	0
Sodium	18	12	13	8	12	10
Phosphorous	3	2	2	2	3	7
Zinc	3	1	1	1	1	6
Calcium	19720	21670	22010	22770	22600	22790
Barium	0	0	0	0	0	0
Magnesium	47	46	47	47	46	43
Titanium	0	0	0	0	0	0
Molybdenum	0	0	0	0	0	0
Vanadium	**225**	**121**	**147**	60	**108**	42

Table II: Evidence of poor combustion conditions

Table II above shows the analysis results of lubricant drains collected from six cylinders in which all readings are normal except for Vanadium, which is very high in cylinder Nos. 1, 2, and 3. This indicates that fuel is contaminating the cylinder lubricant and that the respective injectors need to be checked and the pistons inspected for blow-by.

Confirmation of Adequacy of Lubrication

Engine builders recommend cylinder lubricant feed rates based on the power of the engine and their field experience over the years. The tendency has been to propose higher cylinder lubricant feed rates to combat piston deposit and liner wear problems. In recent years there have been large increases in the recommended feed rate, and daily consumption of cylinder lubricant has become a major cost item.

Adjustments to cylinder lubricant feed rates, either increase or reduction, are typically made with insufficient knowledge of the cylinder lubrication conditions. The engine operator usually follows the engine manufacturer's recommendation. The Chief Engineer may also make adjustments to the Manufacturer's Recommendation based on his own experience, current operating conditions and visual inspection of the piston and cylinder liner.

Cylinder Lubricant Drain analysis can provide information about the lubricant conditions to enable the engine operator to make an intelligent decision about the need for an increase or decrease in the cylinder lubricant feed rate, and the degree of the adjustment.

Engine hours	**New Oil**	**2140**	**3050**
Sample No.		Cyl No.3	Cyl No.3
Sample Date		14.09.96	08.11.96
Physical Properties			
Viscosity cst @ 100C	19.86	21.2	25
Water Content %wt	0.05		1.19
TBN (D2896) mg KOH/g	68.7	41.19	50.3
TAN (664) mg KOH/g		3.11	5.9
Sooty Insolubles (%wt)	0.1	0.4	0.5
Dispersancy (%)	95	92	85
Spectrochemical Analysis units ppm			
Iron	5	8	30
Lead	0	8	2
Copper	0	4	1
Chromium	0	0	0
Aluminium	0	11	11
Nickel	0	22	20
Silver	0	0	0
Tin	0	1	1
Silicon	25	17	15
Boron	0	3	0
Sodium	26	0	0
Phosphorous	9	56	88
Zinc	7	74	97
Calcium	23700	**78900**	25600
Barium	0	2	8
Magnesium	53	0	0
Titanium	0	0	0
Molybdenum	0	0	0
Vanadium	0	71	68

Table III: Cylinder lubricant condition during "running in"

During the running in period it is customary to over-lubricate, which is demonstrated in Table III where at 2140 total engine operating hours the calcium in the drain oil is 3 times the normal level due to a great part of the lubricant being burned. Then at 3050 total operating hours, after reduction of the feed rate, the quantity of calcium in the cylinder lubricant drain is normal.

Table III also shows that, after reduction of the lubricant feed rate, the iron wear particles are still very low at 30ppm and the TBN high. This indicates that a further reduction in cylinder lubricant feed rate might be made without the wear rate increasing significantly. Wear particle values of 100 – 150ppm of iron, or even 300ppm, would be normal and acceptable wear values.

Planning the life span of the diesel cylinder liner

Analysis of the cylinder lubricant drain oil can permit the engine operator to plan the life of the liner by reducing the cylinder lubricant feed rate to a level which gives a desired or an acceptable rate of liner wear.

It can be a false economy to over-lubricate to minimise the wear of the liner. The cost of the lubricating oil may be balanced against the replacement cost of the liner, such that a liner could be planned to require replacement at 70,000 hours, or about 10 years. Maintenance of a liner wear rate of, say, 0.02mm per 1,000 hours, however admirable the achievement, benefits nobody if the liner is then going to have a working life expectancy long after the ship has been scrapped.

Comparison of lubricant costs and cost of liner replacement suggests that acceptance of higher wear rates with a view to replacing liners more frequently, even at 50,000 hours, is an economic proposition.

Assuming a vessel with a 6-cylinder 700mm bore engine develops 20,000 bhp:	**Case 1**	**Case 2**	**Case 3**
Cylinder Oil Feed Rate (gms/bhp hr)	1.2	1.1	1
Consumption per day (Liters)	626	574	522
Consumption per Month (Liters)	15,026	13,774	12,522
Consumption per Year (Liters)	180,313	165,287	150,261
Consumption over 10 years (Liters)	1,803,130	1,652,870	1,502,609
CLO cost for 10 years (US Dollars)	$1,803,130	$1,652.869	$1,502,608
Cost Savings over 10 years		**$150,260**	**$300,521**
Liner Wear Rates (mm/1,000 hrs)	0.04	0.06	0.08
Maximum allowable wear (in theory)	4.2	4.2	4.2
Years before renewal	15	10	8
Liner Wear Rates (mm/1,000 hrs)	0.04	0.06	0.08
Maximum allowable wear (in practice)	3.5	3.5	3.5
Year before renewal	13	8	6

Table IV: Comparison of Cost of Cylinder Lubrication at Feed Rates of 1.2g/ 1.1g/ and 1.0g with cost of liner replacement over a period of 10 years/ 70,000 hours.

Calculations for cost savings: Cylinder Lubricant Feed Rate v. Liner Life Span

The purchase cost of each liner is approximately US$22,000.
The purchase cost for six liners will be US$132,000.

Assuming removal and installation cost US$5,000 per liner:
Then total cost for replacement of all 6 liners will be US$162,000.

When renewing liners at 56,000 hours/ 8 years then, for comparison purposes, the interpolated cost of renewal for a 10 year period will be US$202,500.

When renewing liners at 42,000 hours/ 6 years then for comparison purposes, the interpolated cost for a 10 year period will be US$273,000.

Net savings on the above lubrication costs shown in Table IV less liner renewal costs over a 10 year period for a reduction in lubricant feed rate:

- from 1.2g to 1.1g will be $1,502,609 – US$202,500 = **US$1,297,609**
- from 1.2g to 1.0g will be $3,005,217 – US$273,000 = **US$2,729,217**

Acid condensation

The amount of acid condensation on the liner wall increases with an increase in the sulphur content of the fuel, with an increase in the temperature and pressure of combustion, and with a reduction in the skin temperature of the liner wall.

It is the opinion of the Authors that the increase in the amount of acid, which condenses on the liner wall, is probably one of the main reasons for engine manufacturers increasing their recommended cylinder lubricant feed rates over the past 15 years.

During this time the average sulphur content in marine fuels has not increased over this period of time.

However the increase in engine combustion temperatures and pressures has raised the dew-point of the acid such that condensation can take place at liner wall temperatures as high as 150^0C, whereas earlier theory was that there was no condensation above 130^0C. Ref

Because a fuel with Sulphur content of 3.5% will produce more acid than a fuel containing 2.0% Sulphur, it follows that a ship regularly bunkering lower sulphur fuel can operate safely with a lower cylinder lubricant feed rate than one regularly bunkering high sulphur fuel.

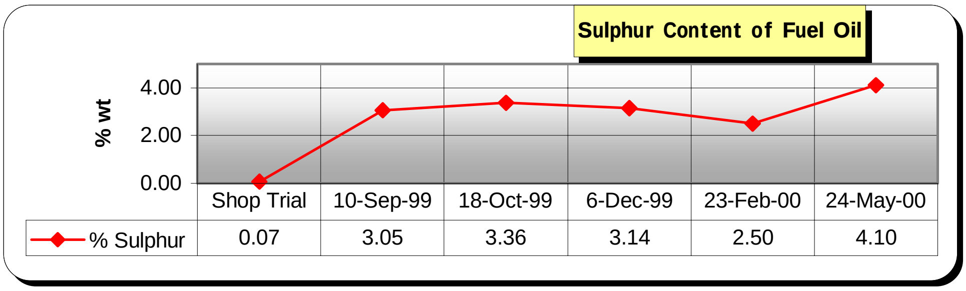


Table V: Sulphur content of fuels lifted by a ship over recent months.

Analysis of the cylinder lubricant drain oil will indicate the amount of reserve alkalinity when operating on different fuels, different engine loads and with different jacket temperatures.

The authors' observations point to an alkalinity reserve of 30TBN in the drain oil as being usually sufficient to maintain liner wear due to the corrosive attack of acid condensation at an acceptable level.

Adjustment of cylinder liner jacket cooling is important to ensure that acid condensation is kept to a minimum by maintaining a higher liner skin temperature, within the restriction of temperature at which the Cylinder lubricating oil can maintain correct lubrication as recommended by the engine manufacturer and lubricant supplier.

Information provided by regular Cylinder lubricant drain analysis allows the operator to adjust the lubricant feed rate to allow for changes in the sulphur content in the fuel as shown above in Table V.

Table V records the sulphur content of fuels used in an engine during the shop trial and subsequently during operation in 1999 and 2000. CLO drain analysis also allows the operator to correct situations of over- or under-cooling of the liners.

An example of the effect of fuels of different sulphur content on the cylinder lubricant drain condition is shown in Table VI. The ships, **Vessels A and B**, are sister vessels operating between the same ports, but, at the time of sampling of the CLO drains, lifting fuels with different characteristics.

Unit No.	Sulphur content in Fuel	CLO Feed (gms/bhp hr)	Vis @100C	TBN	Iron
Vessel A					
4	**2.27**	1.25	28.6	54.7	50
5		1	22.3	52.4	42
9		0.75	23.4	44	59
10		0.75	26.2	**29.1**	**113**
12		0.75	48.8	39.1	37
Vessel B					
4	**3.94**	1	26.4	**19.5**	**900**
5		1	23.4	26.1	523
10		1	24.2	25.2	656

Table VI: A comparison of the effect on the cylinder lubricant of sulphur content in the fuel and lubricant feed rates.

The reserve TBN of the drain from the **Vessel A** is generally high and corrosive wear is correspondingly low as seen from the iron content in the drain samples.

On the other hand, the reserve TBN of the drain from the **Vessel B** is relatively low with correspondingly and corrosive wear is seen to be from the iron content in the drain samples.

The reason for the lower TBN in the drains of the **Vessel B**, despite generally higher cylinder oil feed, indicates high acid deposition. This was noted as due to the higher sulphur content in the fuel being used by **Vessel B**. A similar effect could have been noted due to under cooling of the liner walls.

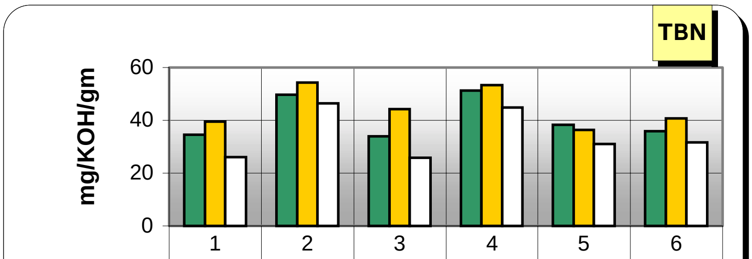
	Vessel A	Vessel B
Density	0.9712	0.9883
Viscosity	721	347
Water	LT 0.1	0.5
MCR	8.3	15
Sulphur	2.27	3.94
TSP	0.01	LT 0.01
Ash	0.03	0.02
V	75	73
Na	15	23
CCAI	826	849

Table VII: The fuel in use at the time of sampling

Vessel A results indicate clearly that when the drain TBN is low (Unit No.10), the iron content is correspondingly high due to an increase in corrosive wear. It can also be seen that the units with lower CLO feed rate register a lower TBN at the drain.

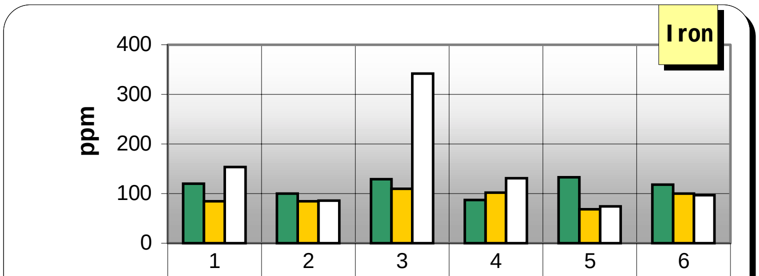
Water separation

Table VIII below demonstrates how the low TBN values in the drain samples from Units No.1 and No.3 of a 6 cylinder 800mm bore engine correspond with the high Iron from the same units in the following Table IX. The Authors' observation is that when TBN of the cylinder lubricant drain oil drops below 30TBN then corrosive wear increases and can be detected in the iron content.



	1	2	3	4	5	6
18-Nov-99	34.6	49.6	33.9	51.3	38.3	35.9
30-Jan-00	39.6	54.3	44.2	53.3	36.3	40.9
23-Apr-00	26.1	46.5	25.8	44.9	31.2	31.8

Table VIII: Consecutive TBN values for each Cylinder Unit 18 Nov/ 30 Jan/ 23 Apr



	1	2	3	4	5	6
18-Nov-99	120	100	129	87	133	118
30-Jan-00	85	85	110	102	69	100
23-Apr-00	154	86	342	131	74	97

Table IX: Consecutive Iron values for each Cylinder Unit 18 Nov/ 30 Jan/ 23 Apr

Detection of high wear rate as indicated by the Iron ppm value in the drain sample should lead to an investigation by ships staff to detect the cause of the problem. Study of other cylinder lubricant drain parameters can frequently give an indication of the cause. In this particular case the source of the high wear could have been related to running in of new rings as indicated by the piston running hours.

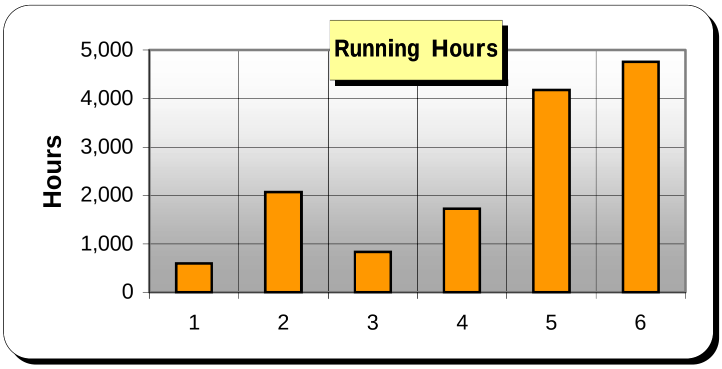
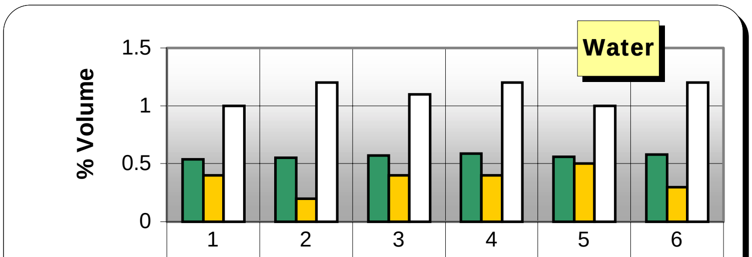


Table X: Running hours for each piston unit since last overhaul

However the low TBN figure indicates that the source of the problem was elsewhere and was eventually traced to a blocked water separator drain line.



	1	2	3	4	5	6
18-Nov-99	0.54	0.55	0.57	0.59	0.56	0.58
30-Jan-00	0.4	0.2	0.4	0.4	0.5	0.3
23-Apr-00	1	1.2	1.1	1.2	1	1.2

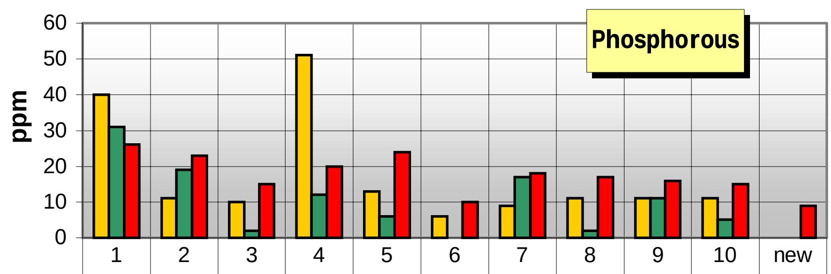
Table XI: Consecutive water values from each Cylinder Unit 18 Nov/ 30 Jan/ 23 Apr

All units show high water. An under piston inspection confirmed that the water was flooding the under piston space of Unit No.3. The excessive influx of water was sufficient to affect all the cylinder lubricant drains but the damage was only being caused to No.3 unit, which is nearest to the air cooler and water separator.

Performance of piston rod glands

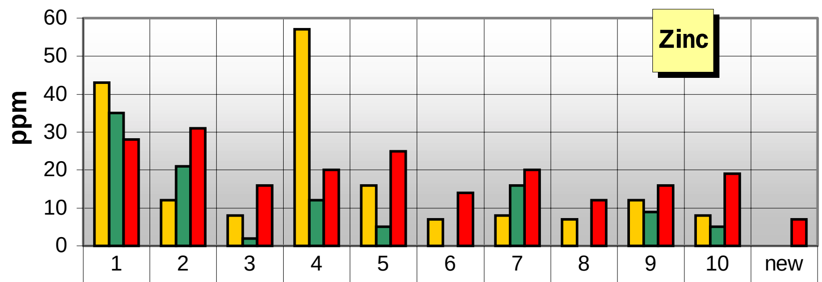
Due to wear or bad alignment of the piston rod gland, cylinder lubricant can leak down into the engine sump causing contamination of the system oil and consequent risks of fouling of the under side of the piston crown leading to burning and cracking of the piston crown.

When the piston rod gland is not providing an efficient seal cylinder lubricant leaks down into the crankcase system oil and, at the same time, system oil leaks up into the scavenge space. Evidence of the leakage can be observed in the cylinder lubricant drain oil as witnessed by Table XI and Table XII.



	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	40	11	10	51	13	6	9	11	11	11	
25-Apr-00	31	19	2	12	6	0	17	2	11	5	
23-May-00	26	23	15	20	24	10	18	17	16	15	9

Table XI: Consecutive phosphorous values from each Cylinder Unit



	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	43	12	8	57	16	7	8	7	12	8	
25-Apr-00	35	21	2	12	5	0	16	0	9	5	
23-May-00	28	31	16	20	25	14	20	12	16	19	7

Table XII: Consecutive zinc values from each Cylinder Unit

TheTables XI and XII show high Phosphorous and Zinc values for Units No.1 and No.3 as analysed on the 24th March. They indicate that there is considerable leakage of system oil into the under-piston space. Advice was passed to the ship and action was taken by ships staff. The subsequent analyses indicate reduced leakage, but also show the beginning of leakage taking place in Units 2 and 5.

Performance of fuel additives

There are many fuel additives for use in marine fuels and the ship manager has difficulty in evaluating their performance.

Dispersant type fuel additives help in homogenising the fuel and reducing the problems of asphaltene agglomeration in unstable fuel. The dispersant action can assist in improving fuel atomisation and so has an indirect effect on improving fuel combustion.

A combustion catalyst assists the fuel to burn more completely and to burn with a shorter, hotter flame.

However some additives are more effective than others and some are more expensive and less cost effective than others.

Cylinder lubricant drain analysis can assist the ship manager to evaluate the performance and cost effectiveness of a fuel additive.

The following is an example of the use of lubricant drain analysis to evaluate a combustion catalyst.

A container ship operator wished to evaluate a combustion catalyst fuel additive with a view to evaluating the performance of the fuel additive and justifying the expenditure incurred.

The claim of the additive supplier was that the combustion catalyst improves combustion of the fuel and reduces acid condensation on the liner wall. These properties of the additive lead on to the claim that it would be possible to reduce the CLO feed rate whilst using the additive and maintaining, or even reducing, the liner wear rates.

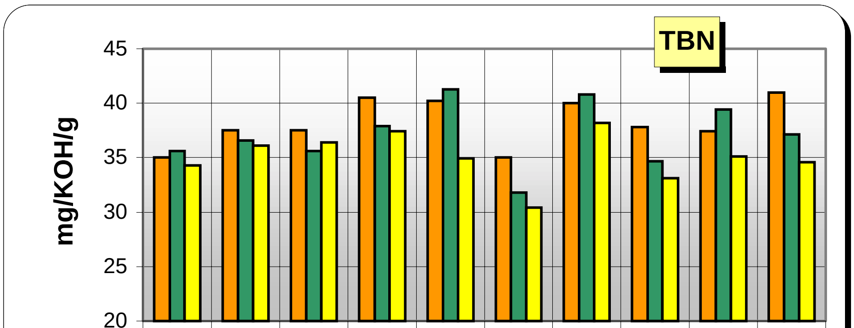
The objective of the manager was to use the lubricant drain analysis programme to monitor cylinder lubricant condition to enable reduction in CLO feed rates to be made with confidence that wear rates were not increasing. The reductions were to be made gradually in steps of 0.05g and only after subsequent drain analyses confirmed that wear rates were not increasing. At the outset the lubricant feed rate was higher than normal but at a level recommended by the engine builder.

To conform with the conservative approach to reducing CLO feed rates the trial is being run over a long period of time and continues at the time of writing this paper.

Prior to applying the fuel additive engine performance and maintenance data were collected, and samples of CLO drain oil were taken. At the start of the trial Total Engine Running Hours were 27,036, and wear rates were as recorded in Table XIII.

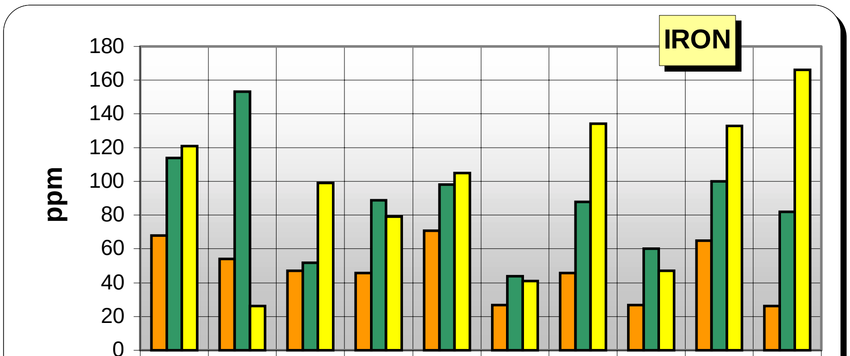
Unit No.	R/H Since last O'haul	Date Last O'haul	R/H Since last O'haul	Liner R/H @ last O'haul	Liner max wear at last overhaul	Liner wear rate since previous overhaul	Liner wear rate since new
1	11,951	03/06/97	6,796	15,095	1.06	*	0.0702
2	13,179	31/03/97	8,124	13,857	0.99	*	0.0714
3	883	07/12/98	14,396	26,153	1.62	0.0403	0.0619
4	14,301	02/02/97	9,156	12,735	0.87	*	0.0683
5	11,951	03/06/97	6,796	15,095	1.06	*	0.0702
6	1,866	20/10/98	13,409	25,170	0.95	0.0157	0.0377
7	13,179	31/03/97	8,034	13,857	0.95	*	0.0686
8	1,866	03/06/97	6,796	15,095	1.15	*	0.0762
9	883	07/12/98	13,422	26,153	1.55	0.0395	0.0593
10	11,951	03/06/97	6,796	15,735	1.21	*	0.0769

Table XIII: Unit operating hours and wear rates prior to trial with the fuel additive



	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10
1-Jan-99	35	37.5	37.5	40.5	40.2	35	40	37.8	37.4	41
9-Feb-99	35.6	36.6	35.6	37.9	41.3	31.8	40.8	34.7	39.4	37.1
8-Mar-99	34.3	36.1	36.4	37.4	34.9	30.4	38.2	33.1	35.1	34.6

Table XIV: Total base number values prior to and at the beginning of the trial



	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10
1-Jan-99	68	54	47	46	71	27	46	27	65	26.1
9-Feb-99	114	153	52	89	98	44	88	60	100	82
8-Mar-99	121	26.2	99	79	105	41	134	47	133	166

Table XV: Iron ppm values prior to and at the beginning of the trial

Tables XIV and XV indicated that TBN and wear rates were at a satisfactory low level. Scavenge port inspection at the start of the trial also showed that the pistons were in clean condition, rings operating freely and liner surface in good condition. The operating history of the engine also confirmed good conditions, which would be difficult to improve on.

Over a period of 16 months the CLO feed rate was reduced in steps of 0.05g from an initial rate of 1.4g/bhp.hour to 1.03g/bhp.hour as shown in Table XVI. This represented a considerable saving in cylinder lubrication consumption.

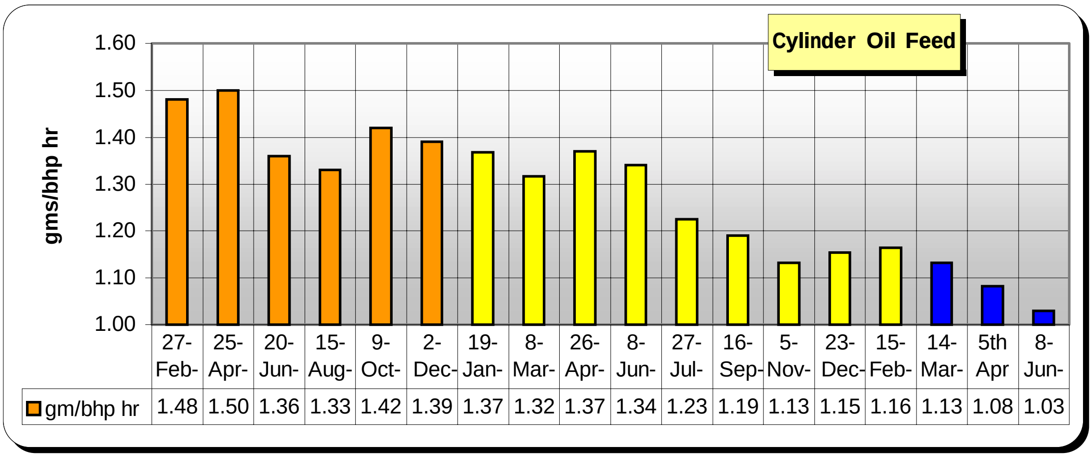


Table XVI: Progressive reduction in cylinder lubricant feed rates from 27 Feb 99 to 8 June 2000

Another apparent benefit from the use of the fuel additive is indicated by the unit operating hours which were extended from lifting pistons about every 15,000 hours to over 22,000 hours for some units as shown in Table XVII.

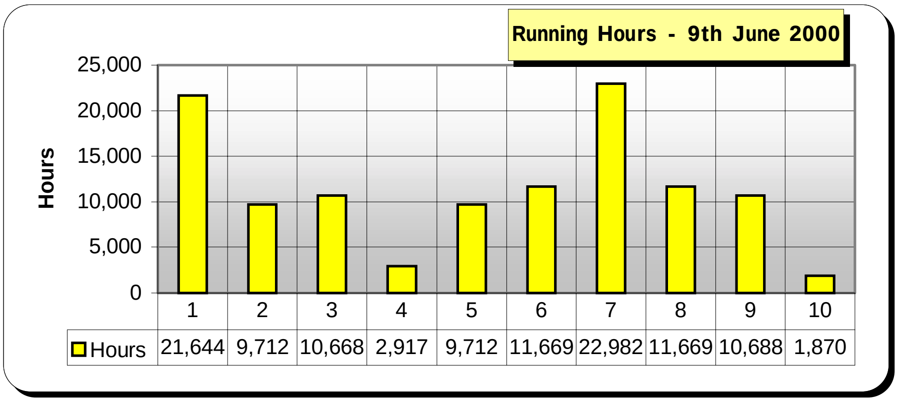
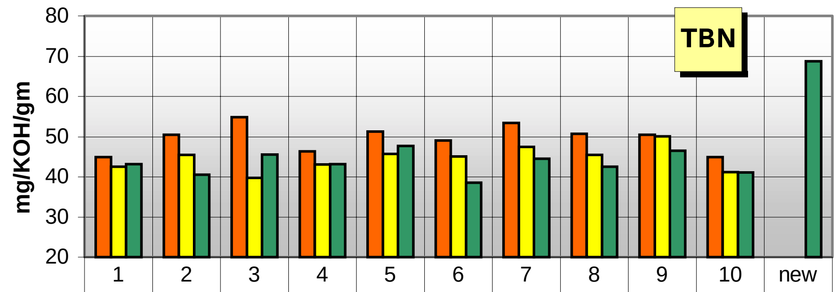


Table XVII: Piston unit running hours since last overhaul

Whilst using the fuel additive CLO drain samples are being taken every month and analysed to check the oil condition and verify wear rates.

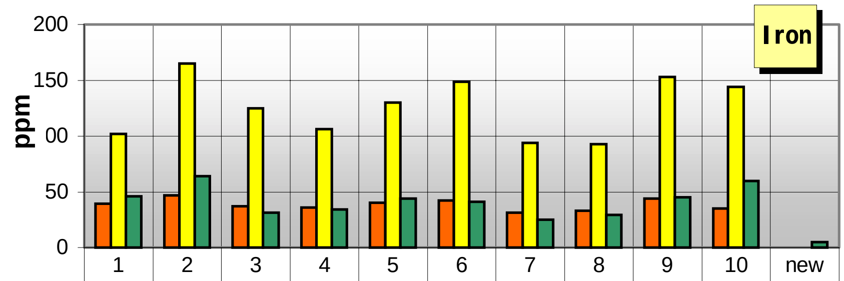
One year after commencement of use of the additive it can be seen in Table XVIII that the TBN values of the CLO drains maintain a high level, despite a 30% reduction in CLO feed rates. At the same time the wear rates, as indicated by the Iron ppm values in Table XIX show that wear is at a very low level.

Incidentally, in the drain analysis collected on 25^{th} April 2000, the water content was high with corresponding increase in Iron content. The cause was found to be a blocked drain line from the scavenge air water separator. The source of the water contamination was located and the fault rectified and Water and Iron content returned to normal in the May 2000 analysis.



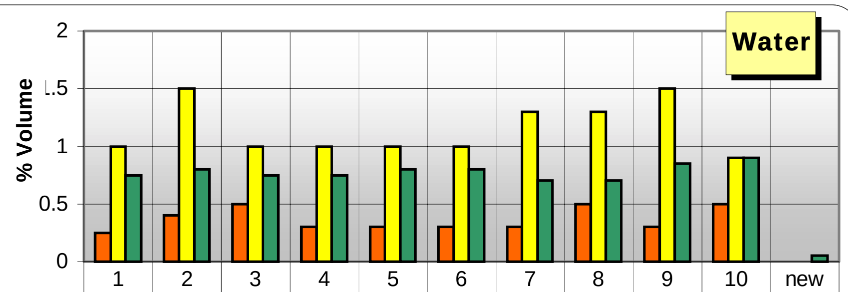
	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	44.9	50.5	54.8	46.3	51.3	49	53.4	50.7	50.4	44.9	
25-Apr-00	42.5	45.4	39.7	43.1	45.7	45	47.4	45.4	50.1	41.2	
23-May-00	43.2	40.5	45.6	43.2	47.7	38.5	44.5	42.5	46.5	41.1	68.7

Table XVIII – TBN values have been maintained at a consistently high and safe value despite the reduction in CLO feed rates.



	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	39	47	37	36	40	42	31	33	44	35	
25-Apr-00	102	165	125	106	130	149	94	93	153	144	
23-May-00	46	64	31	34	44	41	25	29	45	60	5

Table XIX– Wear rates as indicated by Iron ppm are maintained at a low level despite a sudden increase in the April samples.

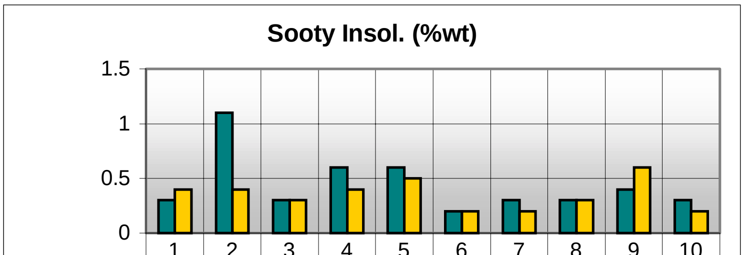


	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	0.25	0.4	0.5	0.3	0.3	0.3	0.3	0.5	0.3	0.5	
25-Apr-00	1	1.5	1	1	1	1	1.3	1.3	1.5	0.9	
23-May-00	0.75	0.8	0.75	0.75	0.8	0.8	0.7	0.7	0.85	0.9	0.05

Table XX – Ingress of water as noted in the April sampling is corrected and the Iron content as shown in Table XIX above returns to normal.

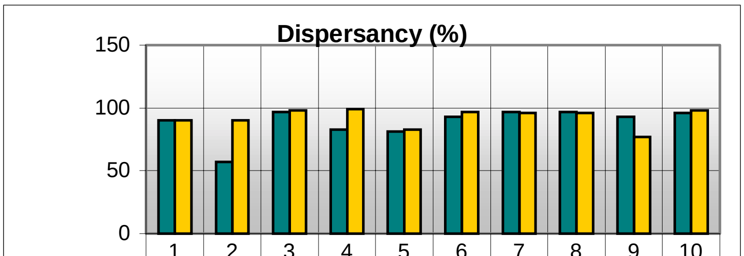
The testing of the fuel additive is current and still continues on this ship with a view to bringing the CLO feed rate down below 0.9 g/bhp.hour. Reduction may continue until it is noted that wear rates, as indicated by the Iron ppm in the drain sample, increase to 150ppm. At the time of unit overhaul a physical measurement is taken to correlate with the Iron ppm.

Combustion conditions whilst using the combustion catalyst are indicated by the Dispersancy and Sooty Insolubles values in the cylinder lubricant drain samples. Tables XXI and XXII show the values in the first months after starting to use the fuel additive and Tables XXIII and XXIV show the Insoluble and Dispersancy values during recent months. The values change with different fuels, and with different engine operating conditions. And, as can be seen in Unit 2 of Tables XXI and XXII the Insolubles will increase and Dispersancy decrease when there is an injector problem.



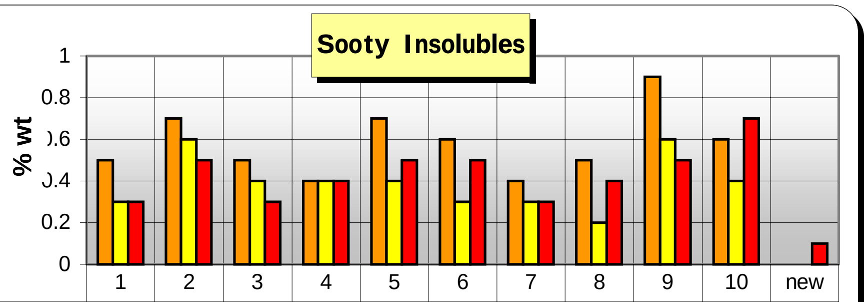
	1	2	3	4	5	6	7	8	9	10
28-Jul-99	0.3	1.1	0.3	0.6	0.6	0.2	0.3	0.3	0.4	0.3
8-Oct-99	0.4	0.4	0.3	0.4	0.5	0.2	0.2	0.3	0.6	0.2

Table XXI: Sooty Insolubles indicate combustion conditions



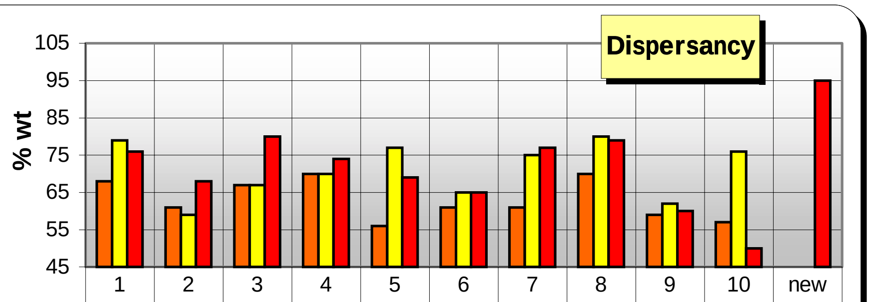
	1	2	3	4	5	6	7	8	9	10
28-Jul-99	90	57	97	83	81	93	97	97	93	96
8-Oct-99	90	90	98	99	83	97	96	96	77	98

Table XXII: Dispersancy confirms combustion conditions



	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	0.5	0.7	0.5	0.4	0.7	0.6	0.4	0.5	0.9	0.6	
25-Apr-00	0.3	0.6	0.4	0.4	0.4	0.3	0.3	0.2	0.6	0.4	
23-May-00	0.3	0.5	0.3	0.4	0.5	0.5	0.3	0.4	0.5	0.7	0.1

Table XXIII – Shows recent Sooty Insoluble values, which are maintained at a satisfactory low level.



	1	2	3	4	5	6	7	8	9	10	new
24-Mar-00	68	61	67	70	56	61	61	70	59	57	
25-Apr-00	79	59	67	70	77	65	75	80	62	76	
23-May-00	76	68	80	74	69	65	77	79	60	50	95

Table XXIV – shows recent Dispersancy values are maintained at a satisfactory high level.

The cylinder lubricant drain analyses indicate that the improvements in combustion and lubrication conditions in the engine are in line with the expectations claimed by the supplier of the fuel additive:

1. It has been possible to reduce CLO feed rate
2. There has been no increase in wear rate
3. Piston cleanliness and combustion conditions have improved, as witnessed by inspections and the extension of time between lifting of pistons, and as confirmed by the Sooty Insolubles and Dispersancy values.

The use of Cylinder Lubricant Drain analysis in the example above is carried out over several months to allow for consecutive, and conservative, reductions in the CLO feed rate. However it is possible to use the same methods over a 6 month period to assess the influence of a fuel additive on combustion conditions.

In Conclusion

The authors have been sampling Cylinder Lubricant drains from large bore, long stroke crosshead engines on a regular basis since the beginning of 1995. The analyses of the drain oil have been complemented by collection of engine performance data and scavenge port inspections to verify the results seen from the drain analyses. In the course of their investigations they have communicated their findings to engine builders and lubricant suppliers who have shown keen interest in the results obtainable from regular sampling.

The Authors' conclusion is that the data available from regular sampling of cylinder lubricant drains can provide a valuable condition monitoring tool for operators of modern cross-head diesel engines.

They are currently setting up a website to provide information on the service they can now offer to operators of cross-head engines with a view, in time, to providing an on-line service.

It is expected that technical managers who use the service will be able to improve engine reliability and make worthwhile cost savings.