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STUDY OF THE RELATIONSHIP BETWEEN CYLINDER LUBRICANT DRAIN CONDITION AND PERFORMANCE PARAMETERS OF 2-STROKE CROSS-HEAD ENGINES

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ABSTRACT

A study of the condition of diesel engine cylinder lubricant drains from modern long stroke large bore cross-head diesel engines over the past 5 years has indicated a relationship between drain oil condition and the maintenance and performance conditions of 2-stroke cross-head diesel engines. By regularly sampling cylinder lubricant drain oil from each cylinder unit it has been possible to determine the optimum lubricant feed rate, monitor the wear rates of each cylinder unit, plan the life span of the liner, check for water contamination, verify the effectiveness of sealing of each piston rod gland, and evaluate combustion conditions.

INTRODUCTION

In 1994 the drain oil condition of two cylinder units of one MAN.B&W 6S80MC engine was monitored by the authors' company over a period of 10,000 hours, and then, in the period from 1995 until 1998, several other large bore MAN.B&W and Sulzer engines were monitored in the same way. As it became clear that monitoring of cylinder lubricant drain oil was yielding very useful information about the performance of the engine, and about the comparative performance of individual cylinder units, the monitoring was extended to all cylinder units of one engine and then to other engines. The authors are now sampling and analyzing Cylinder Lubricant drain oil routinely on all cylinder units of many ships, between 6 and 8 times per year, the frequency being dependent on the voyage schedule.

As sampling has been extended to different engines with different operating conditions, including new-buildings, more knowledge is being accrued about the conditions of combustion and lubrication in the diesel engine, and the relationship between the drain oil condition and engine performance parameters. The studies to date are to be regarded as a step towards understanding more about the combustion and lubrication processes in the cross-head diesel engine.

Cylinder lubricant drain sampling

Analysis of the waste oil, and comparison of the waste oil analyses with new oil analysis, enables conclusions to be drawn about the combustion and lubrication conditions of each cylinder unit. A further comparison, of the waste oil from one cylinder unit with the waste oil from other cylinder units of the same engine, enables comparison of the performance and maintenance condition of each unit against the other units.

By regular sampling from each cylinder unit comparisons can be made with previous sample analyses. The trends demonstrated by regular sampling have been seen to reflect the changing maintenance condition of each unit and the changing combustion conditions as different fuels are lifted with each bunkering, and also the changing lubrication conditions between different brands of lubricant and different methods of cylinder lubrication.

Most engine designs provide for the waste cylinder lubricating oil to be drained from the piston rod diaphragm by a separate pipe from each cylinder unit into a manifold, which carries the waste lubricant into a drain tank for subsequent incineration or landing ashore.

By providing a shut-off cock and sampling cock onto each cylinder unit drain pipe it is possible to take samples of the waste oil. This arrangement is a standard feature of MAN.B&W engines and many Sulzer engines. Some engines require the fitting of the cocks on each drain pipe, or other minor modifications, to be able to take drain samples.

It has been reported [(1)] that, since 1998, two-stroke diesel engines are powering 80% of new buildings. Each of these engines is consuming cylinder lubricant at a feed rate typically between 0.7g and 1.2g per bhp.hour. For a modern large container ship the daily expenditure on cylinder lubrication can be as high as US$2,000 per day, or over US$500,000 per year.

Changing Conditions of Lubrication

Cylinder lubrication conditions have changed considerably over the past 20 years.
There has been continuous development of the diesel engine since its inception, particularly in respect of the power output from each cylinder unit.
The increase in power output has an effect on engine lubrication conditions.

In recent years the increase in power output has coincided with a creeping deterioration in the quality of fuel being burned. The test methods used for marine fuels, however, have not changed to match the changes in fuel quality and, as a result, the two characteristics, ignition quality and combustibility, which have deteriorated considerably, are not yet tested.

The combination of increasing power output and deteriorating fuel quality has had a major influence on cylinder lubrication conditions in modern 2-stroke diesel engines.

Factors Influencing Cylinder Lubricant Condition

1. Engine Development

The increase in power output of modern diesel engines has had the consequence of increasing the amount of cylinder lubricant consumption.

Schenk, Hengeveld and Aabo[(1)] refer to an increase in power per cylinder from a 900mm bore engine, when first introduced in 1982, as developing 4680 BHP, whereas the current model produces 6650 BHP, a 42% increase in power output.

In 1982 the typical cylinder lubricant feed rate for a uni-flow scavenge engine was 0.67g/kWh (0.5g/ bhp.hour), which indicates that the lubricant consumption of such a 10 cylinder 900mm bore engine would be 562kg per day. With a 42% increase in power, and typical lubricant feed rates having increased from 0.67g/kWh to 1.34g/kWh (0.5g to 1.0g/bhp.hour) and more, the lubricant consumption for the current model will be about 1,600kg of cylinder lubricant per day.

The increase in power has also led to an increase in the acid condensation on the liner wall. In addressing the subject of corrosive wear in the same paper[(1)] it is stated that previous opinion was that there would be no acid condensation if liner wall temperature is maintained above 190^{0}C, even when operating on a 5% sulphur fuel and Pmax of 200bar. The paper goes on to state that recent investigations have confirmed acid condensation, and hence corrosive wear, is still a significant factor at temperatures above 190^{0}C, and is occurring with liner wall temperatures up to, and above, 270^{0}C for an engine operating on 3.5% sulphur fuel and firing pressure of 150 bar.

The increase in acid condensation due to the increased power has come as a surprise[(3)] to engine manufacturers and the increased acid condensation has had a marked effect on the diesel cylinder lubrication conditions.

2. Changes in the quality of residual marine fuel

Aabo in his paper “Fuels for Diesels” [(2)] described the modern fuel problem, which the authors see as a matter for particular concern, as “The ignition delay is not the only parameter of importance for the combustion process. The combustion duration may be even more important in terms of piston ring versus liner operation.”

The authors have observed that extended duration of combustion can be the cause of severe cylinder wear, a phenomenon which has been graphically documented by one engine builder in a confidential report for an operator of Sulzer 12RTA84 engines.

To understand the reason for late combustion and the consequent severe liner wear it is useful to consider how marine fuels have been, and still are, changing.

As the demand for automotive and aviation fuels escalated the refineries introduced secondary methods of refining, whereby the residue from atmospheric distillation is subjected to catalytic and thermal cracking to extract a greater quantity of light products. In recent years this has resulted in the viscosity breaking process, the Vis-Breaker, being operated with greater "severity" and the residue of this process becoming more viscous. The high viscosity ''vis-broken'' residue needs to be blended with a low viscosity product, a cutter stock, which will at one time reduce its viscosity, improve its handling and maintain its stability. The most appropriate cutter stock candidates appear to be the distillates from the catalytic cracker. These Low Viscosity and High Viscosity Cycle Oils are notable for having low cetane index and poor combustion characteristics.

Hence as the severity of operation of Vis-Breakers is being gradually increased in refineries around the world, there is a concurrent increase in the amount of Cycle Oil which is blended into the Vis-Broken residue to produce marine fuels to meet the viscosity requirements of ships' engines.

The effect on marine fuels is that ignition, and, more important, combustibility have both been, and still are, deteriorating. The ISO fuel test procedures do not yet provide for measurement of ignition or combustibility so there has been no apparent deterioration in fuel quality over the past 10 years, as stated at the CIMAC Day Fuel Meeting on 30th September 1998

The effect of utilising such fuels in the marine diesel engine has a marked effect on cylinder lubrication conditions, not least due to late completion of combustion, which can burn the cylinder lubricant on the liner wall and lead to dry liner conditions and abrasive wear of the liner wall.

Diesel Cylinder Lubrication

The cross-head diesel engine relies on the injection of cylinder lubricant through the liner wall to lubricate the piston/ liner and, after performing its duties, drains away to waste.

In practice, a large part of the lubricant injected is wholly, or partly, burned. The greater the excess of lubricant over that required for optimum lubrication conditions, and the longer the duration of combustion, the greater the amount of lubricant is burned. Some of the excess lubricant remains as deposits on the piston, and some forms deposits in turbo-chargers and economisers. The residue of 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.

The condition of the lubricant as it drains off the diaphragm carries with it information about the combustion and lubrication conditions in each cylinder unit.

CYLINDER LUBRICANT DRAIN ANALYSIS AND ENGINE PERFORMANCE

1. Analytical tests

The test procedure used by the authors for Cylinder Lubricant drain analysis is to perform 5 physical and 19 spectrographic analyses of each oil sample. **Table I** compares the analysis of a new cylinder lubricant with the condition of the same oil after performing its function in a MAN.B&W S80MC engine:

Table I – Comparison of New and Used Oil

Physical Properties	New Oil	Used Oil
Viscosity @ 100C cst	19.75	23.9
Water %wt	0.05	0.95
TBN mg KOH/g	71.1	25
Sooty Insolubles %wt	0.1	0.8
Dispersancy %	85	63
Spectrographic Analysis ppm		
Iron	6	378
Lead (ppm)	0	0
Copper (ppm)	0	2
Chromium	0	1
Aluminium	0	16
Nickel	0	32
Silver	0	0
Tin	0	61
Silicon	19	28
Boron	17	0
Sodium	20	29
Phosphorous	12	13
Zinc	13	12
Calcium	22600	20045
Barium	0	0
Magnesium	57	69
Titanium	0	0
Molybdenum	0	0
Vanadium	0	125

The changes which take place in the lubricating oil during its passage down the cylinder liner to the drain pipe enable interpretations to be made about the conditions of combustion, maintenance and lubrication of the individual unit.

2. Cylinder Lubricant Feed Rate

The authors have carried out sampling and analysis of Cylinder lubricant drains on a number of ships to check whether the rate of lubrication of each cylinder unit diesel engine is sufficient to provide adequate lubricant to overcome friction between the piston rings and liner wall, and to neutralise acid condensation on the liner wall in order to minimise corrosive wear. In several studies it has been noted that the cylinder lubricant feed rate is excessive and the authors have been able to recommend a reduction.

The accepted method for the calculation of lubrication feed rate is as a multiple of the power of the engine expressed in grammes per kilowatt hour, or grammes per brake horsepower hour. As Engine Manufacturers recommend lubricant feed rates expressed in this way, then, as the power per cylinder unit has developed over the years, so has the amount of lubricant injected. The reasoning behind this method of calculation is open to question, but not within the scope of this paper. Engine Manufacturers and the Cylinder Lubricant Suppliers have, until recently, stated that “the greater the amount of lubricant, the better the operating conditions”.

In 1995 the authors’ company had collected evidence[5] of over-lubrication causing piston deposit problems in an 800mm bore engine lubricated at 1.6g/kWh (1.2g/bhp.hour). Subsequent reduction of the cylinder lubricant feed rate down to 1.2g/kWh (0.9g/bhp.hour) resulted in cleaner piston conditions and reduced liner wear.

It is now accepted[3] [4] that excessive lubrication can lead to heavy deposit formation on the top land and piston crown, cause ring groove deposits and ring seizure, and lead to liner wear and scuffing. One Engine Manufacturer recently stated[4] that lubricating oil feed rate should not exceed 1.6g/kWh (1.2g/bhp.hour), and recommends a rate of 1.3g +/- 0.3g/ kWh (0.97g +/- 0.22g/ bhp.hour), for the time being, whilst investigations continue.

Nevertheless many operators have been reluctant to adjust the lubricant feed rate to a lower level after many years being advised by both the engine manufacturers and the lubricant suppliers that it is not possible to over-lubricate, and “the more lubricant the better”.

The typical Cylinder Oil feed rate range, between 1.0g/kWh to 1.6g/kWh (0.7g to 1.2g/bhp.hour) is very wide and most operators still err towards higher rates despite the growing acceptance that over-lubrication is a possible cause of piston deposits, ring seizure and wear.

Evidence of over-lubrication can manifest itself visually in an engine by:

- Crescent shape white deposits on the piston crown
- Deposits of calcium on the piston top land
- Calcium deposits in the ring grooves and ring seizure

The condition of over-lubrication can be seen in the condition of the drain oil by observing the TBN and Iron values. and, most significantly, when the Calcium value in the drain oil is higher than that in the new oil.

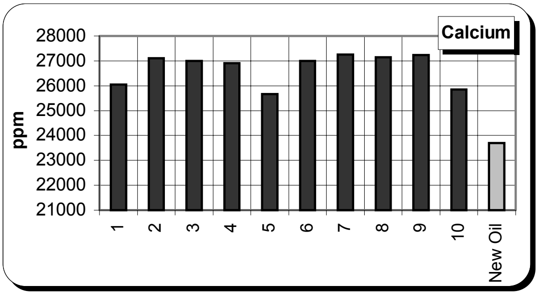


Fig 1 - Calcium values from a MAN.B&W 10L80MC

The Calcium values in **Fig 1** are higher than the 23,700 ppm found in the new oil, which indicates that the drain oil is carrying a lot of lubricant ash from lubricating oil that has been burned.

Reduction of the feed rate to a MAN.B&W 10L80MC engine was monitored(6) – **Fig 2** – under the guidance of the authors, and in agreement with engine manufacturer's recommendations, in steps of 0.067g/kWh (0.05g/bhp.hour). Three sets of drain oil samples were taken over a period of 2,000 hours before any reduction was made and then again, after each reduction, a further set of analyses is taken, before reducing by another step of 0.067gramme.

The aim has been to reduce feed rates towards the lower level recommended by the Engine Manufacturers, as the results of the cylinder lubricant drain analyses confirm the possibility to do so.

The relevant analysis values were monitored during the reduction process to ensure that all lubricant drain values were maintained within safe levels. See - **Figs 3 & 4**.

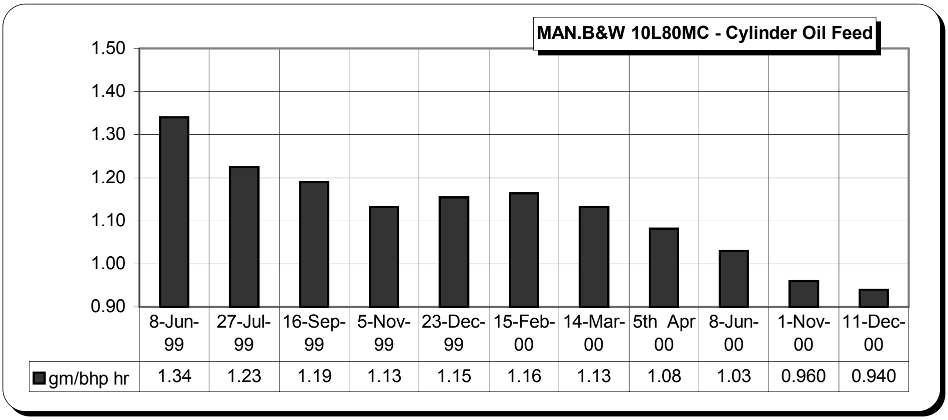
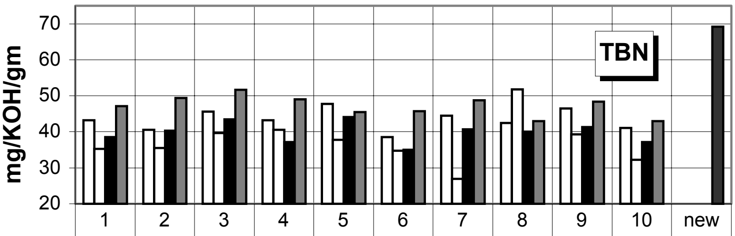
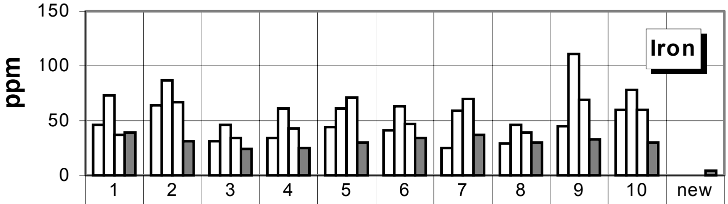


Fig 2 – Progressive reduction of Cylinder Lubricant feed rates



	1	2	3	4	5	6	7	8	9	10	new
23-May-00	43.2	40.5	45.6	43.2	47.7	38.5	44.5	42.5	46.5	41.1	0
13-Jul-00	35.3	35.5	39.7	40.5	37.8	34.7	27	51.8	39.3	32.2	0
6-Sep-00	38.5	40.3	43.5	37.1	44.1	35	40.7	40	41.3	37.2	0
20-Oct-00	47.1	49.4	51.6	49	45.5	45.7	48.7	42.9	48.4	42.9	69.2

Fig 3 - TBN values during progressive reduction in Cylinder Lubricant Feed



	1	2	3	4	5	6	7	8	9	10	new
23-May-00	46	64	31	34	44	41	25	29	45	60	0
13-Jul-00	73	87	46	61	61	63	59	46	111	78	0
6-Sep-00	37	67	34	43	71	47	70	39	69	60	0
20-Oct-00	39	31	24	25	30	34	37	30	33	30	4

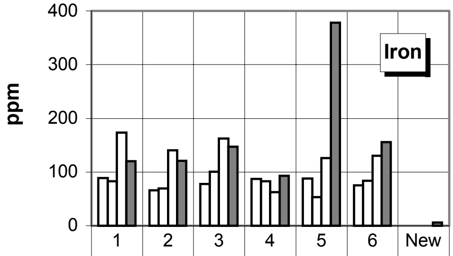
Fig 4 – Iron values during progressive reduction in Cylinder Lubricant Feed Rate

3. Cylinder Liner Wear Conditions

Liner wear can result both from abrasive and corrosive wear.

Analysis of the Iron and Alkalinity values in the cylinder lubricant drain oil taken by the authors has provided a check on the amount of wear taking place between the piston rings and the cylinder liner, and has been able to confirm the adequacy of the alkaline reserve to counter corrosive wear. A case in point was demonstrated by analyses of drain oil from a MAN.B&W 6S80MC engine.

Tabulation of the Iron values in the drain oil, see **Fig 5**, from all engine cylinders permitted comparison of performance conditions between cylinder units.



	1	2	3	4	5	6	New
25-Jul-00	89	66	78	87	88	75	0
1-Aug-00	83	69	101	83	53	84	0
6-Oct-00	173	140	162	63	126	130	0
30-Oct-00	120	121	147	93	378	156	6

Fig 5 – Iron values demonstrating sudden liner wear in No.5 Cylinder Unit

Plotting of Iron values for each engine cylinder from consecutive drain samples enabled the trends in liner wear to be evaluated. At overhaul intervals the wear trends noted by drain analysis were confirmed by physical measurements.

At the same time the alkalinity values of the drain oil were able to confirm sufficient reserve to minimise the risk of corrosive wear taking place. The alkaline reserve can be affected by the amount of sulphur in the fuel, water in the scavenge air supply, liner wall temperature and the power being developed [(1)].

4. Combustion Conditions

Conditions of poor atomisation and incomplete combustion are evident in the analysis results of cylinder lubricant drains.

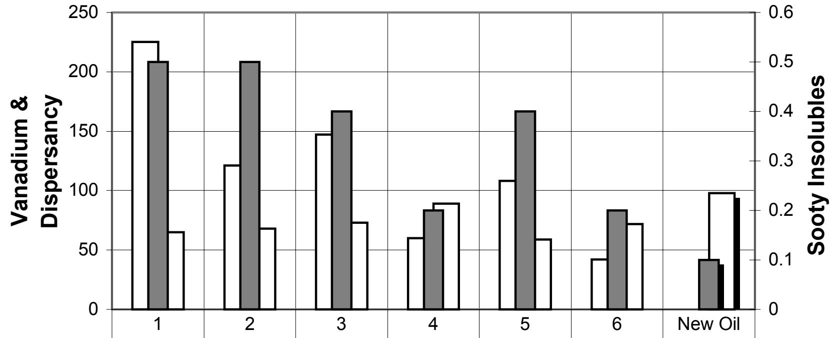
By comparing the drain analysis results from each cylinder unit from a MAN.B&W 6S80MC the individual combustion performance of each cylinder unit could be interpreted.

Fig 6 show analyses from an engine with poor combustion performance on one unit. There is good correlation between the analysis values whereby poor combustion condition in Unit 1, indicated by high Vanadium, low Dispersancy and high Insolubles, contrasts with good combustion in Unit 4 having low vanadium, high Dispersancy and low Insolubles.

By carrying out a comparison over several sets of samples taken at 1000 hour intervals, the trends, in terms of an improvement or deterioration in combustion conditions could be interpreted. When noting a deteriorating trend the operator can be alerted to the need for maintenance, be it the changing of an injector or the lifting of a piston with seized rings.

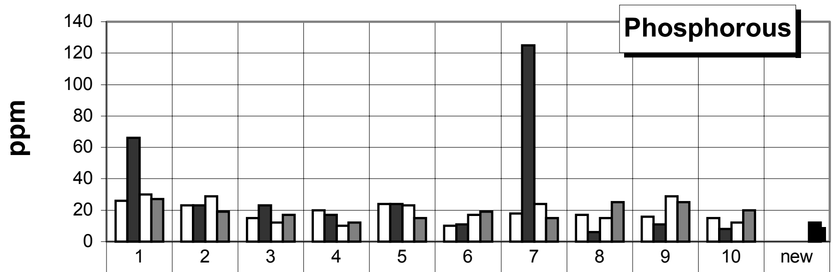
5. Checking performance of the piston rod gland

Analysis of Cylinder Lubricant drains from a MAN.B&W 10L80MC engine demonstrated incidence of an impending problem with piston rod of Unit 1 and a serious problem with Unit 7 as shown in **Fig 7**. Leakage of system oil from the crankcase upwards through the piston rod stuffing box was quickly noted and corrected.



	1	2	3	4	5	6	New Oil
Vanadium	225	121	147	60	108	42	0
Dispersancy	65	68	73	89	59	72	98
Sooty Insol.	0.5	0.5	0.4	0.2	0.4	0.2	0.1

Fig 6 – Analysis values indicate poor combustion in Unit 1and good combustion in Units 4 and 6.



	1	2	3	4	5	6	7	8	9	10	new
23-May-00	26	23	15	20	24	10	18	17	16	15	0
13-Jul-00	66	23	23	17	24	11	125	6	11	8	0
6-Sep-00	30	29	12	10	23	17	24	15	29	12	0
20-Oct-00	27	19	17	12	15	19	15	25	25	20	12

Fig 7 – Sudden leakage of system oil at Units 1 & 7, detected and corrected

If a piston rod gland is not maintaining a good seal then cylinder lubricant drains contaminate the crankcase oil. Evidence of system oil contamination is readily picked up when system oils are monitored by the lubricant supplier, but the supplier's analysis does not define which unit is leaking. Contamination by cylinder lubricant drain oil causes an increase in TBN in the system oil, lowering its resistance to water contamination and causing a build up of deposits on the underside of the piston crown. The increase in TBN of the system oil can however be masked because of the concurrent need for more make up of system oil as it leaks up into the under-piston space.

Leakage of system oil into the under-piston space is readily seen when analysing cylinder lubricant drain oil. The comparative performance of the piston rods of each unit can be noted from each unit sample, and the trend of leakage noted over a range of several samplings

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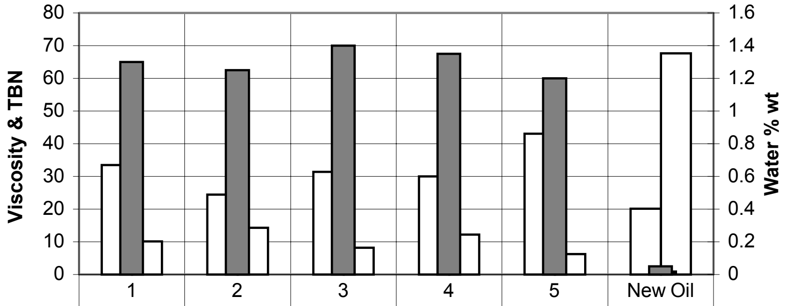

	1	2	3	4	5	New Oil
Viscosity	33.52	24.4	31.43	30.01	43.1	20.11
TBN	10.1	14.3	8.2	12.2	6.3	67.7
Water	1.3	1.25	1.4	1.35	1.2	0.05

Fig – Effect of High water contamination in the Cylinder Lubricant

6. Water contamination

The presence of an excess of water in the diesel cylinder can have a detrimental effect on the ring and liner wear conditions[3] as was demonstrated in the analyses from a Sulzer 5RTA72 engine – **Fig 8**.

Water is reported[3] to cause an increase in the formation of acid and an increase in liner wear. The authors have observed that water contamination is accompanied by an increase in viscosity, probably due to emulsification of the cylinder oil, and also by a marked drop in the alkalinity and increase in Iron values. Although the mechanism is not clear to the authors by which the lubricant, and the lubrication process, breaks down, it is understood that the water may cause an increase in the formation of a dilute and highly corrosive acid, and a breakdown in the alkaline component of the cylinder lubricant, reducing its effectiveness in neutralising acid formation.

Study of the parameters allowed recommendation of prompt remedial action to the operator before the problem of water contamination developed. An alert to the possible source of the water can be indicated, as, in this case, a blocked water separator drain, or be it exceptional ambient humidity, and correction before excessive wear took place.

Other Applications of Cylinder Lubricant Drain Analysis

The authors have investigated the use of Cylinder Lubricant drain analysis for other evaluations:

1. Performance Comparison of different Lubricant Brands

Drain Analysis has been applied to compare the performance of different brands of cylinder lubricant in one Sulzer 7RTA84 engine where Owners wished to check the performance of one cylinder lubricant with another before making a commercial decision to change to a new supplier. Four cylinders were lubricated with the current lubricant and another brand was used in the other three cylinders. The analyses were able to confirm that the performance of both lubricants were similar, indicating that there would be no technical reason why the new lubricant should not be used.

2. Performance Comparison of different Cylinder Lubrication Systems

The authors' company is currently providing the Drain Analysis service assist in comparing the performance of a new design of diesel cylinder lubrication equipment installed on two units of a MAN.B&W 12K90MC engine, whilst the balance ten continue to be lubricated with conventional equipment.

3. Planning the life of the liner

The authors are discussing with some engine operators the use of Cylinder Lubricant drain analysis to reduce the lubricant feed rate to give acceptable, rather than minimum liner wear rates.

Evidence collected by the authors and others[3,4] indicates that the cost of lubrication to achieve low wear rates in the region of 0.04mm/ 1000 hours can sometimes be uneconomic. Adjusting lubrication feed rate to achieve wear rates in the region of 0.05mm to 0.06mm/ 1,000 hours, or other acceptable wear figure, can be cheaper in terms of cost of liner replacement compared to the cost of the lubricant to maintain a wear rate in the region of 0.04mm/ 1000 hours.

As shown in **Table II**, the cost of cylinder lubrication at the upper end of the range recommended by the Engine Manufacturers, of 1.6g/kWh (1.2g/bhp.hour), can result in expenditure over 10 years of US$1,800,000 for a 700mm bore engine.

This may be compared with the cost of lubrication at the lower end of 1.0g/kWh (0.75g/bhp.hour) of US$1,130,000 per year for the same engine, a difference of US$670,000 over a ten year period.

Given that a typical purchase and installation cost for a 700mm liner would be approximately US$27,000, it prompts the question whether a balance should be made, between the cost of lubrication and that of liner replacement, to optimise operating costs.

Changes in engine loading and changing fuel quality, as well as operating and maintenance factors, can affect liner wear. To be able to plan liner life span the authors recommend close monitoring of engine performance, lubricant condition and fuel data

Table II – Comparison of Cylinder Lubricant costs at different feed rates

Example: 6-cylinder 700mm bore engine develops 20,000 bhp:	Upper limit 1.6g/kWh	Mid range 1.35g/kWh	Lower limit 1.0g/kWh
Cylinder Oil Feed Rate (gms/bhp hr)	1.2	1	0.75
Consumption per day (Litres)	630	520	390
Consumption per Year/ 7,000 hours in Litres	180,000	150,000	113,000
CLO cost for 10 years (US Dollars) @ US$1.00/ litre	$1,800,000	$1,500,000	$1,130,000
Cost Difference over 10 years/ 70,000 hours		**$300,000**	**$670,000**

CONCLUSIONS

Cylinder lubricant drain analysis has opened a new source of information to help determine engine performance conditions, providing the superintendent with additional information to make engine maintenance decisions. Important to note is that Cylinder Lubricant drain analysis can detect a problem, such as ring and liner wear, water contamination of the cylinder lubricant, and piston rod gland leakage, before it would be picked up by conventional methods of inspection. Furthermore, by combining cylinder lubricant drain analysis with the physical inspection of piston condition through the scavenge ports, more precise maintenance decisions can be made.

The need for regular piston inspection is recognised by most operators. However, the lower educational standard of some ships' staff may mean that piston inspection cannot always be relied upon to provide as much valid information about piston and liner conditions as would be the case with inspection by an experienced superintendent or specialist engineer.

Despite the fact that cylinder lubricant analysis does not require the authors, as providers of the analysis service, to go on board customer ships it has, nevertheless, been their practice to make engine inspections. They encourage ships' staff to participate in the piston inspections with a view to training engine room staff in the observation and photographic recording of piston and liner conditions. Visual inspection does, nevertheless, have its limitations as the authors' experience has indicated that drain analysis can pick up a wear problem which has not been noted during visual inspection of pistons, in other words, before the wear became a serious problem.

As a further step towards a more comprehensive engine performance monitoring service the authors have been collecting engine performance data from selected ships. The combination of regular monthly engine performance data, photographic records of piston and liner condition, together with the data derived from cylinder lubricant drain analysis has enabled a more detailed and specific interpretation of engine performance condition to be provided to engine operators. The objective is to provide the fleet manager and superintendent with data in a readily understood form to enable him to take prompt and appropriate action to maintain economic operation, engine reliability and optimum performance.

The authors have already collected a considerable amount of engine performance data from some containerships and tankers using cylinder lubricant drain analysis and look forward to reporting their findings from these ships and others in due course.

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