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Doubling Oil Drain Intervals - The Reality of Centrifugal Bypass Filtration

Paul Coombs, Ian Cox and Andrew Samways
The Glacier Metal Company Limited

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ABSTRACT

The extension of Diesel engine oil drain intervals is now widely recognised as an essential part of the global effort to reduce the amount of waste oil generated by society. Engine end users are demanding units which require less frequent and less costly servicing, OEM's are responding by employing a number of techniques to meet this need.

Bypass centrifugal oil cleaners are known to be effective in prolonging engine service life. This paper demonstrates, through a series of long term engine tests, that the use of a modern bypass centrifugal oil cleaner in combination with a full-flow metal screen can safely double the oil drain interval of an 8 litre sized diesel engine. The results also show the centrifuge to have a beneficial effect on the condition of engine components even with the extended drain period.

INTRODUCTION

Emission limits legislation for diesel engines has now been agreed in many countries. These limits are set to get progressively tighter as we move into the next century [1]. Originally framed for on-highway vehicles, the legislation in many countries is now being extended to cover off-highway, construction and agricultural vehicles. This emissions clampdown has prompted engine designers to take a fresh look at the diesel engine and a number of design innovations have reached the marketplace in recent years. Many of the changes in engine design (for example the introduction of exhaust gas recircultion (EGR)) have resulted in increased contaminant loading of the lube oil.

Whilst manufacturers have been tackling the emissions issue diesel engine users have been demanding ever longer service intervals to offset the rising costs of service labour, new oil and filters and used oil disposal. The result is that the lube oil of the modern diesel engine is being asked to survive longer and tolerate higher levels of contaminant than ever before. Modern oil additive formulations help to contain in suspension the high contaminant levels while synthetic base stocks are increasingly being used to prolong oil life. The control of insolubles and viscosity levels still remain limiting factors in service interval extension[2].

The application of bypass centrifugal oil cleaners to diesel engines has long been known to be a powerful tool in controlling lube oil contamination [3][4][5]. However recent engine developments have raised new questions about the limits of centrifuge performance. The series of tests detailed in this paper were designed in conjunction with a major engine manufacturer to define the ability of a bypass centrifuge, in conjunction with a long life cleanable full-flow screen, to enable the extension of oil drain intervals on a modern diesel engine. The test results show the effect on a highly rated modern engine using a CG4 oil of a centrifuge and screen filtration system with extended oil drain intervals compared to the standard barrier media filtration system for the engine.

THE ENGINES

Two engines were taken from the production line and tested by the manufacturer to ensure that they both met the required performance criteria prior to being shipped to T&N Technology at Rugby, England. The engines were supplied with a standard sump having a maximum lube oil capacity of 35 litres.

The lube oil used for the tests was a SAE 15W40 grade CG4 classification. The total volume of oil used for these tests came from a single production batch and was supplied by the engine manufacturer.

The engines were designated "Engine 1" and "Engine 2" and were tested consecutively in a computer controlled engine test cell using a water brake dynamometer.

ENGINE LUBE OIL FILTRATION

Engine 1 was fitted with the standard OEM filtration of a single full-flow barrier media filter rated at 40µm absolute. Engine 2 was fitted with a single full-flow mesh screen plus a bypass oil cleaning centrifuge.

The filtration system layout for both engines is illustrated in figure 1.

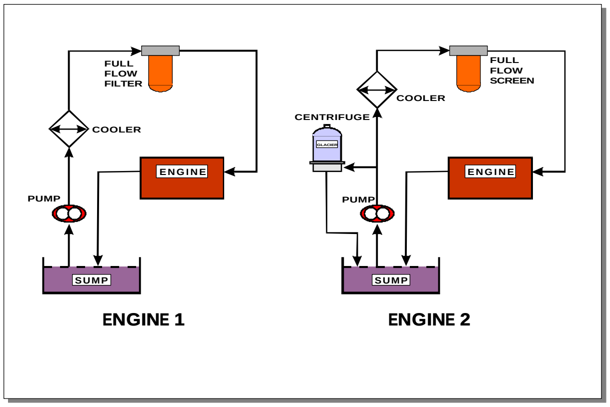

Figure 1. Filtration layout for both engines

THE CENTRIFUGE – The bypass centrifuge used on Engine 2 was a commercially available unit of a cleanable nature having a dirt holding capacity of approximately 600ml. This unit has a quoted performance of 7000rpm and 10.5 litres/min throughput at an inlet pressure of 7 bar with SAE30 oil @ 75°C [6].

THE FULL-FLOW METAL SCREEN – The full-flow metal screen fitted to Engine 2 was manufactured from woven stainless steel wire cloth rated at 45µm nominal, 58-63µm absolute. This material was pleated to form a filtration unit with similar dimensions to the OEM full-flow barrier media filter.

SCREEN AND CENTRIFUGE FILTRATION METHODOLOGY

The centrifuge operates in bypass processing approximately 10% of the lube oil before returning it to the engines sump. As the centrifuge is not a barrier type filtration device, it does not rely upon a filtration media to remove the contaminant particles from the lube oil. Unlike a barrier media bypass filter which only removes particles of contaminant larger than the pore size of the media, a centrifuge removes particles based upon their relative density.

Oil is pumped into the centrifuge by the engine's oil pump at pressure. The oil is directed into a hollow spindle where it exits via a cross hole and into the centrifuge rotor. The rotor becomes full of pressurised oil which is then allowed to exit via two tangentially opposed nozzles in the rotor base. This causes rotation of the free spinning rotor assembly thus generating centrifugal force within the rotor. As particles of dirt carried by the lube oil enter the rotor, they are subjected to this centrifugal force which causes them to migrate radially outward to the inner surface of the rotor wall. Over time, these particles of dirt build up to form a solid annulus of contaminant.

By using centrifugal force, the centrifuge is capable of removing a wide range of particles which in theory extends into the sub-micron range at the extreme and includes those that are not captured by the full-flow filter. This is confirmed by analysis of the dirt collected by a centrifuge which reveals a capability to remove small particles of less than one micron in size [7]. Figure 2 shows the principle of a centrifuge in more detail.

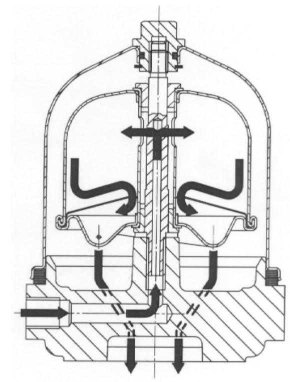

Figure 2. Principle of operation for a bypass oil cleaning centrifuge.

By using a centrifuge to remove the bulk of the contaminants either produced or ingested by the engine, the role of the full-flow filter device is changed. The purpose of the full-flow metal screen in place of the full-flow barrier media filter is to process the full-flow of the engine's lubricating oil. As the oil is pumped to the engine components the screen prevents large particles of debris from reaching the lubricated surfaces and causing catastrophic failure.

ENGINE TEST PROCEDURES

Both engines were tested using a standard engine test procedure recommended by the engine manufacturer. The test procedure known as a modified life cycle test was designed to wear the engine over a period of 2100 hours. Figure 3 shows the engine test cycle in more detail.

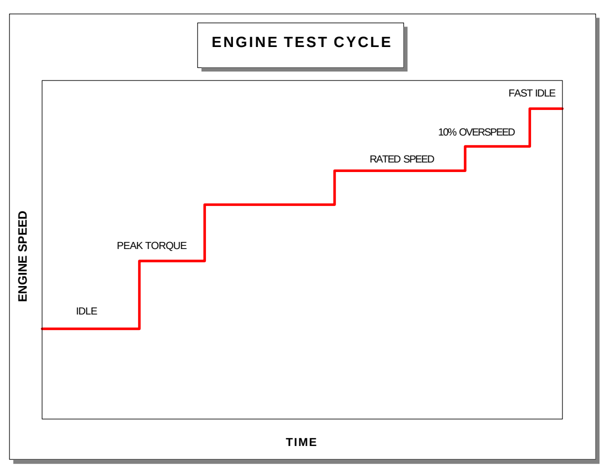

Figure 3. Engine Test Cycle

ENGINE BREAK-IN

Prior to shipping the engines, the manufacturer briefly ran both units to ensure that the power and torque outputs were comparable and within recommended limits.

Prior to the commencement of the 2100 hour test, both engines were run for a period of 80 hours each, using the modified life cycle test illustrated in figure 3. This break-in cycle was conducted using the break-in oil specified by the engine manufacturer.

Upon completion of the 80 hour break-in cycle, the procedure detailed in table 1 was adopted.

Table 1. Initial Service Procedure

	Engine 1	Engine 2
Lube oil	Drain Break-In oil. Fill with test oil.	Drain Break-In oil. Fill with test oil
Filtration	Replace full-flow barrier media filter	Replace centrifuge rotor cover

OIL DRAIN PROCEDURES

Engine 1 was run according to the engine manufacturers standard procedure. The lube oil was drained and replaced and the full-flow filter was replaced at 350 hour intervals. In order to test the ability of the centrifuge and screen filtration system to maintain the condition of Engine 2’s lube oil over extended oil drain intervals, the lube oil was drained and replaced every 700 hours effectively doubling the recommended oil drain interval.

The full-flow metal screen remained in service without inspection or cleaning for the entire test duration of 2100 hours, the pressure drop across the screen being continuously monitored. Although the centrifuge used was of a cleanable type, the rotor bowl was replaced rather than cleaned every 700 hours at the oil drain. This procedure allowed inspection and analysis of the collected contaminant at a later date. The service details for both engines are summarised in table 2.

Table 2. Service Timetable.

	Engine 1	Engine 2
Every 350 Hours	Drain and replace lube oil. Remove and replace full-flow filter.	
Every 700 Hours	Drain and replace lube oil. Remove and replace full-flow filter.	Drain and replace lube oil. Remove and replace centrifuge rotor cover

OIL ADDITIONS PROCEDURE

At the start of each oil drain interval, each engine was filled with fresh oil to the maximum mark on the oil level indicator. Both engines were then run until the oil level reached the minimum mark on the oil level indicator. Thereafter, the oil level was maintained at the minimum level by adding fresh oil to the engine every 24 hours at a quantity equivalent to the engines daily oil consumption. Oil additions to both engines were recorded to enable meaningful comparisons to be made between the oil analysis results.

ENGINE DATA

Main engine characteristics were monitored during the testing of both engines including Power, Torque, Blowby, Oil Pressure, Oil Temperature, Oil Additions and Oil Consumption. To ensure a truly representative test, the performance of both engines was matched as closely as possible throughout the 2100 hour duration.

OIL AND SLUDGE ANALYSIS

OIL ANALYSIS – In order to asses the performance of the two filtration systems, 50ml oil samples were taken from each engine every 48 hours and these samples were analysed by an independent laboratory. Spectrographic analysis was used to determine the levels of wear elements. Total insolubles measurements were made using the modified blotter spot technique. Other physical properties such as viscosity and TBN were measured using standard oil analysis techniques.

SLUDGE ANALYSIS – The dirt removed by the centrifuge was collected and subjected to spectrographic analysis and Scanning Electron Microscopy to determine its composition.

TEST RESULTS

ENGINE PERFORMANCE – Figure 4 shows the power and torque produced by both engines over the duration of the test. The two engines were selected by the manufacturer to have very similar performance characteristics. Engine 1 produces slightly more power than Engine 2 and this is largely attributed to differences in engine build. The fueling rate and fuel temperature was consistent between the two engines.

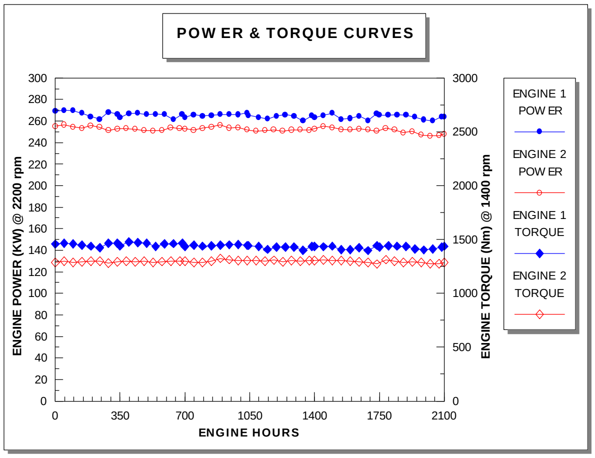

Figure 4. Engine Power and Torque Comparison.

Figure 5 shows the cumulative oil additions for both engines. This graph shows that Engine 2 received fewer additions over the duration of the test which is thought to be due to reduced cylinder component wear (see section on engine wear). The lower oil consumption of Engine 2 effectively results in higher lube oil contaminant loading due to the lower level of fresh oil additions and hence, less dilution of the contaminated sump oil.

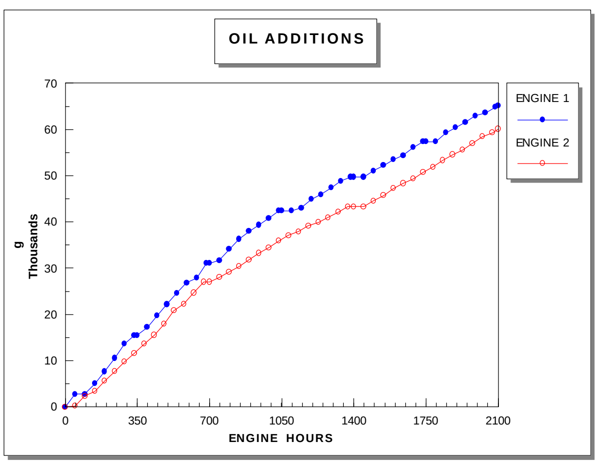

Figure 5. Cumulative Oil Additions for Both Engines.

OIL ANALYSIS RESULTS – Figure 6 shows the level of iron in the lube oil of both engines. It can be clearly seen that the level of iron in the oil samples of Engine 1 increase consistently over the 350 hours oil drain periods. The increased level in the final oil drain can be explained as an increase in the amount of natural wear taking place within the engine. This trait was as expected by the engine manufacturer.

The rate of iron accumulation in the oil of Engine 2 is substantially lower than that of Engine 1. Iron contamination in the oil of Engine 2 takes approximately twice as long to reach the same level as that of Engine 1.

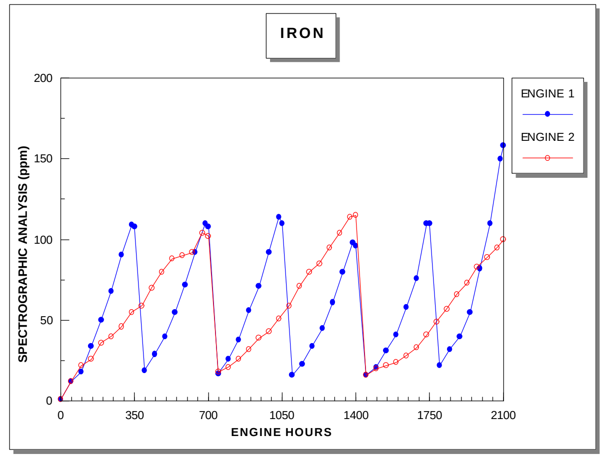

Figure 6. Spectrographic Oil Analysis of Iron in Lubricating Oil for Both Engines.

This is probably due to a combination of two effects 1) the centrifuge is removing the dense contaminant wear particles from the lube oil and 2) the engine is actually wearing less due to better lube oil contaminant control on Engine 2. The rate of increase of iron in the lube oil of Engine 2 is consistent over the test and does not exhibit the rapid increase towards the end of the test that is apparent with Engine 1. This increase in iron levels when approaching 2100 hrs is a normal feature of the engine type when running this test cycle and is an indication of the condition of wearing parts, especially cylinder components.

Figure 7 shows the kinematic viscosity of the oil in both engines, measured at 40°C. Oil viscosity is a major measure of an oils ability to flow through the engine. Generally, as the lube oil becomes loaded with dirt, the viscosity of the lube oil rises. Figure 7 clearly shows that the rate of viscosity increase of the lube oil used in Engine 2 is similar throughout the 2100 hour test and is considerably lower than that of the oil used in Engine 1. It can also be seen that the rate of viscosity rise for Engine 1 is variable and increases over the duration of the test.

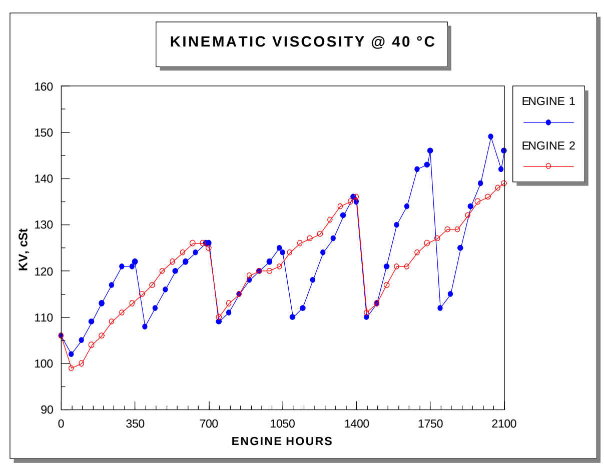

Figure 7. Oil Viscosity.

Figure 8 shows the level of total insolubles within the lube oil of both engines. The level of total insolubles indicates the level of dirt within the lube oil. As the oil becomes loaded with dirt, the total insolubles level rises. The lube oil becomes unservicable at a predetermined insolubles level and hence must be changed. The engine manufacturer has determined that a total insolubles level of 3% by weight should not be exceeded for this engine. Figure 8 clearly shows that the total insolubles level of Engine 2 increases at a slower rate than that of Engine 1. It can also be seen that the rate of increase in Engine 2 is reasonably repetitive and controlled. Towards 2100hrs the oil in Engine 1 exceeds the 3% condemnation limit. This is due to wear in the power cylinder components which is supported by the iron levels shown in figure 6.

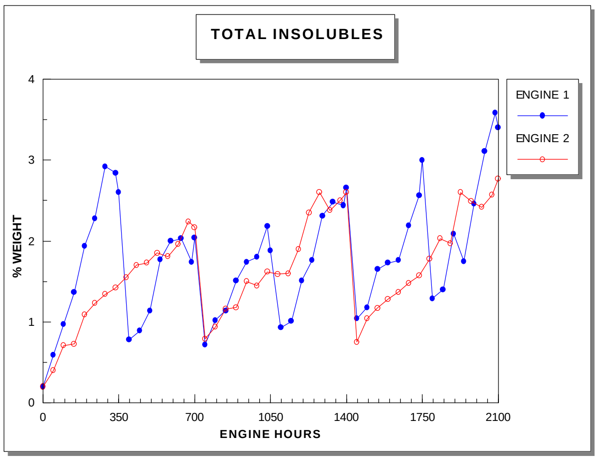

Figure 8. Total Insolubles.

Figure 9 shows the remaining active dispersancy within the lube oil of both engines. This is a measure of the oils ability to disperse particles of soot thus preventing agglomeration. As the oil becomes loaded with dirt, the level of remaining dispersancy reduces. Despite the extended drain intervals of Engine 2 the level of active dispersancy in this engine falls at a similar rate to that of Engine 1. It is thought that the mechanism responsible for this is the removal from the lube oil of contaminant particles by the centrifuge before they become fully saturated with dispersant molecules [8].

An oil's Total Base Number (TBN) is a measure of the oil's reserve of alkalinity which is used to neutralise acids produced by combustion and the reaction of water with other contaminants. As the lubricating oil is used, its ability to neutralise acids is reduced as the alkalinity additives are consumed.

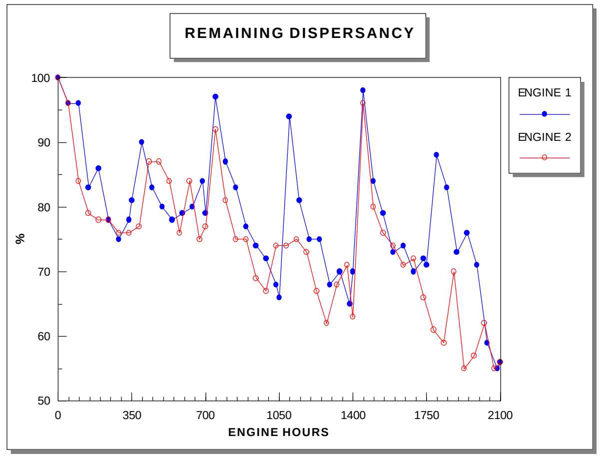

Figure 9. Remaining Dispersancy.

Figure 10 compares the TBN of the lube oil in both engines for the duration of the test. The TBN of the oil used in Engine 1 depletes rapidly over the 350 hour drain interval. The TBN of the oil used in Engine 2 reduces initially at a similar rate to that of Engine 1, but after approximately 250 hours the rate of depletion reduces, showing a tendency to "level off". The TBN level of the oil in Engine 2 does not fall below the 2 mg KOH/g warning level recommended by the engine manufacturer during any of the service intervals.

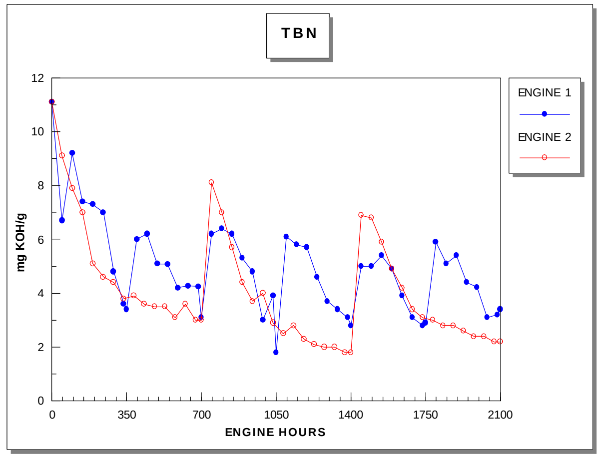

Figure 10. TBN.

The continued effectiveness of the oil's basisity up to 700 hours is demonstrated by the levels of lead found by the spectrographic analysis of the samples. The lead levels at oil drain for Engine 2 were consistently low, reaching between 6 and 12 ppm at the end of each 700hr period.

CENTRIFUGE SLUDGE – Over the duration of the test, the centrifuge fitted to Engine 2 removed a total of 1,389g of dirt from the lube oil. Figure 11 shows the breakdown of this total over the three oil drain periods. From this analysis, it was determined that the centrifuge removed more dirt from the lube oil as the engine hours increased and hence component wear increased. Through spectrographic analysis, we are able to understand in more detail the composition of the centrifuge dirt.

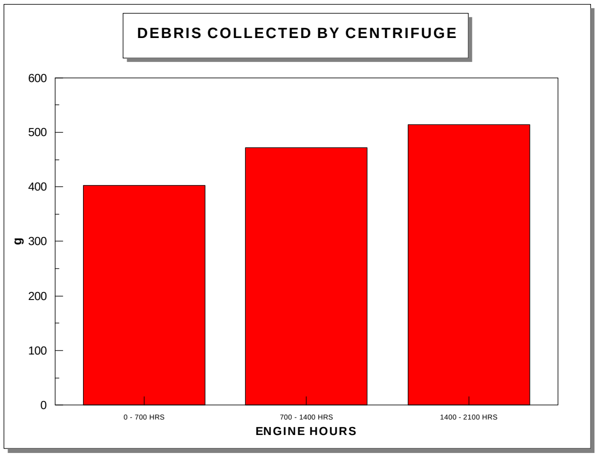

Figure 11. Debris Collected by Centrifuge.

Figure 12 illustrates the averaged analysis of the dirt collected by the three rotor covers. This indicates that the majority of the dirt is soot.

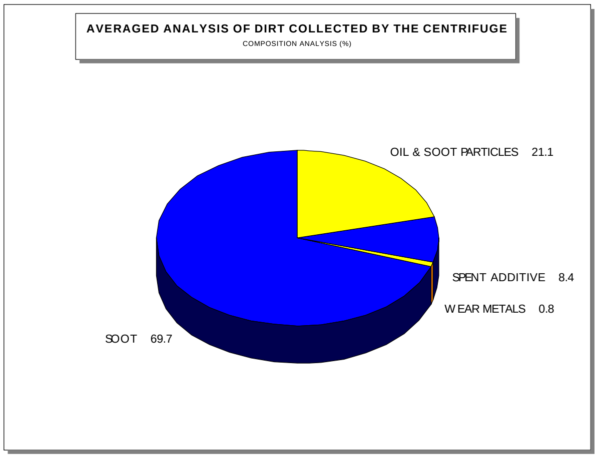

Figure 12. Analysis of Dirt Collected by Centrifuge.

Figure 13 shows the three centrifuge rotor covers used in the tests. The first cover is on the left of the picture and the last is on the right.

Figure 13. Centrifuge Rotor Covers from Engine 2.

When viewed closely, the amount of dirt collected and its consistency can be seen more clearly. All three rotors displayed compacted dirt of a dry nature with a minimal amount of lubricating oil present. Figures 15, 16, 17 show the three rotor covers individually in more detail.

Figure 14. Centrifuge Rotor Cover from Engine 2 (First Oil Drain - 0-700 Hours)

Figure 15 - Centrifuge Rotor Cover from Engine 2 (Second Oil Drain - 700-1400 Hours)

Figure 16 - Centrifuge Rotor Cover from Engine 2 (Third Oil Drain - 1400-2100 Hours)

ANALYSIS OF THE FULL-FLOW SCREEN **-** Over the duration of the test on Engine 2, the full-flow screen collected a total of 294mg of contaminant. This debris was analysed to reveal its composition and the results are illustrated in figure 17.

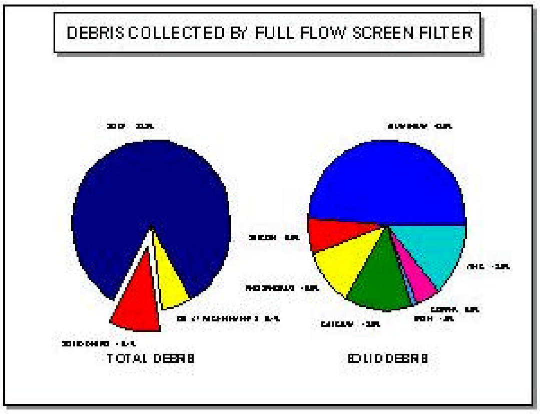

Figure 17 - Analysis of Debris Collected by Full-flow Screen.

The minimal amount of debris collected by the full-flow screen can be attributed to the ability of the centrifuge to remove the bulk of the contaminants generated or ingested by the engine.

ENGINE WEAR

On completion of the engine tests, both engines were returned to the manufacturer for analysis. The engines were disassembled and inspected to compare the effects of the two filtration systems on the wearing components. All the major engine components from Engine 2 were found to be visually cleaner that those removed from Engine 1. Components from Engine 1 exhibited signs of normal wear. Components from Engine 2 exhibited consistently less wear than those from Engine 1. Of particular note were the connecting rod bearings which showed a worn and wiped appearance in Engine 1 with debris scratches. The bearings from Engine 2 however exhibited a good condition with only one shell from the twelve exhibiting wear to the overlay.

CONCLUSION

As engine designs continue to evolve to meet future emissions legislation, the contaminant loading placed on the engines lubricating oil will increase. Maintaining lubricant performance under these conditions will require a filtration system capable of consistently removing large volumes of contaminant from the lube oil.

The results of these engine tests demonstrate that the combination of a bypass centrifuge and a large pore size, mesh, full-flow screen can effectively control both the fine, carbonaceous contaminants that cause viscosity increase and engine wear, and the large solid particles which cause short term damage to engine components. Furthermore, it has been shown that the benefits of the centrifuge and screen system with extended oil drain intervals are sustainable over the working life of the engine.

It is concluded therefore that centrifuge and screen filtration technology provides a real alternative to conventional barrier media filtration in extended drain applications.

ACKNOWLEDGMENTS

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