FEDERAL MOGUL

DIESEL ENGINE LUBE OIL CONTAMINATION CONTROL INTO THE NEXT MILLENNIUM

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The recent rapid growth in the environmental awareness of both manufacturers and consumers has led to considerable pressure on society to reduce the amount it throws away. With this background, the current trends in diesel engine design are to reduce tailpipe emissions and extend oil drain intervals. Unfortunately it is often the case that strategies for reducing tailpipe emissions such as EGR and changes in piston geometry have the effect of adding to the contamination level of the lube oil. This paradox has prompted amongst many diesel engine designers a radical review of methods for controlling lube oil contamination.

Different manufacturers have taken different approaches to the lube oil contamination problem and a brief review of some of these are included in this paper. One solution however is emerging as a clear leader in the field of contamination control, namely Centrifugal Bypass Filtration. A collection of results are presented from a range of laboratory, engine and vehicle tests, all of which confirm the ability of Centrifugal Oil Cleaners to effectively control lube oil contamination. The data collected show that it is consistently possible to double oil drain intervals by fitting a bypass centrifuge system, even on engines with EGR and high dispersancy oils.

INTRODUCTION

By the time the European emissions regulations for Diesel engines came into force with Euro 0 in 1990 many manufacturers had already altered their design philosophy to place "low emissions" high on the list of design priorities. Since then the limits for NO_x have virtually been cut in half and are set to halve again by the time Euro IV is achieved.

It is perhaps the Particulate Matter limits however which are of more concern. From their inclusion at Euro I they will fall by almost 70% with the introduction of Euro IV. These dramatic reductions in tailpipe emissions whilst good for the environment are placing enormous demands on conventional engine technology (1).

The increasing use of EGR has helped manufacturers stay within NO_x limits but the technology cost has been high. Combustion chamber PM levels have increased and piston temperatures are achieving new heights. Combine this with higher ring packs to reduce crevice volume and the need for features such as piston cooling jets becomes apparent.

In the frenzy to reduce the amount of harmful material exiting engines via the exhaust and breather systems it is easy for designers to lose sight of the fact that many of the contaminants have not been reduced or eliminated but have simply been contained, mainly in the lubricating oil. During this period of low emissions design another design driver has emerged, that of fuel efficiency. The fuel efficient design philosophy tends to view oil in a rather poor light. Oil requires power from the engine to firstly overcome its fluid drag and pump it around, and secondly power to carry the weight of the oil. This thinking has led to the call for less viscose oils with lower oil pressures and smaller sump volumes.

It is an unfortunate consequence therefore that the race to be green has resulted in diesel designers attempting to squeeze more contaminants into less oil whilst at the same time expecting it to cope with higher temperatures and operate longer between changes. To achieve acceptable lubricant performance under these conditions it is obvious that effective contamination control methods must be employed.

STRATEGIES FOR CHANGE

Most engine manufacturers and oil suppliers have recognised the need for change in the way lubrication systems are applied to new generation diesel engines and a number of different strategies have emerged to cope with the problems caused by low emissions technology.

Oils

Of all the research areas by far the largest amount of effort has gone into the development of high-tech lubricants to meet the new challenge. Work has generally centred in two areas, i) resistance to thermal degradation over extended periods and ii) the ability to contain large amounts of contaminant with minimal loss of performance.

The first area is largely being addressed by the development of partially and fully synthetic lubricants. Oil companies have developed a range of different processes in this field but the goal is essentially the same, to produce a lubricant with greatly enhanced resistance to elevated temperatures and thermal shock which is capable of maintaining that resistance throughout its (long) working life. More often than not the condemning factor for synthetic lubricants is contamination caused by foreign matter rather than oxidation and break down of the lubricant itself.

In general increases in contaminant concentration increase the viscosity of the fluid and the larger the size and concentration of the contaminant the higher the increase in viscosity. This in turn requires the consumption of more power by the oil pump whilst at the same time reducing the effective performance of the lubricant. Work on increasing the contamination tolerance of oils has been going on for some time and has produced some impressive results. The basic goal being to develop additives which will firstly prevent contamination building up on engine surfaces and will secondly suspend the contaminant as very fine particles in the lubricant, preventing it from agglomerating and thus reducing it's impact on lubricant viscosity.

There is little doubt that oils have developed rapidly in the last few years however with technical advance has come spiralling costs with oil companies trying to reposition themselves in the market in the anticipation of selling less oil but at a higher price (2). It is also questionable how much further oil development has left in reserve for future emissions clampdowns.

Design

There is a relatively simple method of reducing the concentration of contaminant in an engine lube system which some manufacturers have adopted. That is to enlarge the size of the sump, thus effectively diluting the problem. In some cases this act has been seen as a short term solution to enable longer drain intervals to be achieved with an existing engine design. In other cases it appears to be part of a deliberate strategy to extend drain periods and reduce the effect of contaminants on lubricant performance.

Although effective in reducing contaminant concentrations, increasing sump size has a number of disadvantages. The increase in engine weight reduces fuel economy whilst the increase in thermal mass can reduce thermal efficiency under varying load conditions but the biggest penalty is that of cost. A 25% increase in sump size means a corresponding increase in oil change cost and with some of the current synthetic oils costing operators in the region of £5.00 per litre the cost soon becomes significant.

Other design changes which are being employed to reduce PM emissions include timing changes, new piston geometries and ring pack designs, very high injection pressures and higher levels of EGR.

In general however design changes are placing a higher load on the lube oil, be it thermal or contaminant tolerance and it seems unlikely that high-tech oils alone will be capable of coping with the associated increases in soot loadings and thermal shocks.

Filtration

The "obvious" way to reduce the level of contaminant in lube oil is to remove some of it. This is the traditional approach and it would indeed be difficult to find an engine which does not use oil filtration today. The problem in dealing with combustion debris however is one of size. Most current full flow barrier media filters are rated at between 15μm and 50μm depending on whether one is observing the absolute or nominal rating. Recent work has shown that soot particles (the prime particulate contaminant in modern diesel lube oil) have sizes in the range 20 - 30nm and these fuse together to form larger particles in the range of 0.2 - 0.3μm (3,4,5,6). It is clear therefore, that conventional full flow barrier media filters are at best an order of magnitude larger in pore size than the particles they are trying to remove, and hence they are not capable of controlling the growing amounts of combustion debris finding its way into the lube oil.

In addition to full flow barrier media filtration techniques, very fine barrier media bypass filtration techniques have been developed by a number of engine/filter companies and are becoming increasingly popular. Bypass filtration typically filters <10% of the oil supplied by the pump through a fine barrier media filter before either entrainment to the full flow stream or returning to the sump.

Japanese engine manufacturers have been working with filter companies for many years to product progressively finer barrier media bypass filters with increasingly elegant and complex designs. Coupled with the traditional lower dispersancy oils found in Japan they have achieved some success, however the demands from European and North American markets for lower emissions and longer drain intervals, together with the increased use of high dispersancy oils has caused these manufacturers major problems and many are now looking for alternative methods of contamination control (7).

An alternative form of bypass filtration using a self driven centrifuge has been used by some leading manufacturers such as Scania, Renault and Mack for a number of years and is now being further developed to address the issues created by the reduction in the particulate level emissions regulations. Because centrifugal separation relies on density differences to separate out contaminant from the lube oil rather than particle size it has the potential to remove very small contaminant particles (<<1μm), such as those generated by high injection pressures for example. In addition, because a centrifuge has no filter media they are immune to the "plugging" problems experienced with very fine barrier filters.

Figure 1 shows the results of a laboratory test set-up to directly compare the life and dirt tolerance of a barrier media full flow filter when either i) a fine barrier media bypass filter is also present in the system and ii) a bypass centrifuge is connected in the system. The filters were connected in a simulated vehicle lubrication circuit and SOFTC-2A test contaminant was added at a steady rate of 20.83g/hr. The flows and pressures in the system were monitored and the system was deemed to have failed when the full flow filter bypass valve opened.

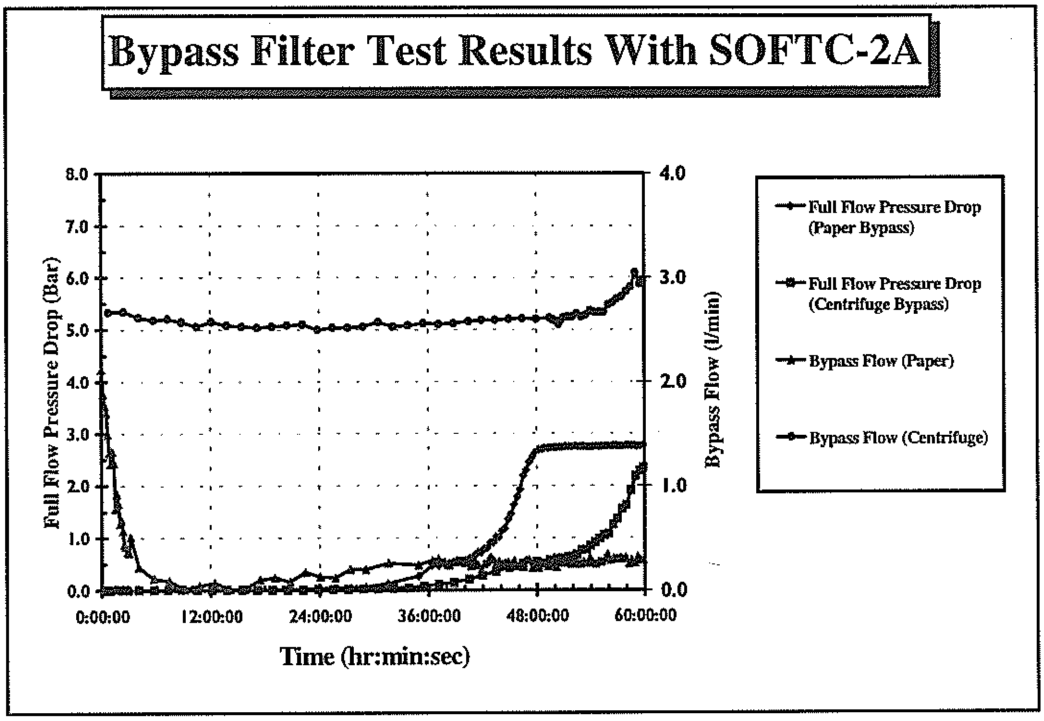

Figure 1.

It can be seen that the barrier media bypass filter blocks (flow ⇒0) at an early stage in the test whereas the centrifuge continues to operate even when the full flow filter eventually blocks. full flow filter life can also be seen to be significantly extended.

It is clear therefore that centrifugal oil cleaners present a very real opportunity to remove significant amounts of contaminant from the lube oil, thus improving the oil condition and extending its useful life as well as reducing component wear rates (8,9).

Current Position

A brief review of several major truck manufacturers in the 12*l* size range reveals the differing approaches to lube oil contamination control being used to cope with the current Euro II compliant emissions control technology.

It can clearly be seen from Figure 2 that the bypass centrifuge is firmly established in the strategy of several manufacturers and is assisting them to meet the demands of this generation of engines. Of particular interest is the comparison between the DAF 95XF and the Mercedes Actros. It can be seen that Mercedes have employed a "big sump" policy together with a high spec. synthetic oil whereas DAF use a much smaller sump in combination with a bypass centrifuge to achieve the same 100,000 km drain interval.

Engine Lubrication Systems
European Engines 11-13L Displacement

	Drain Interval (Km)	Sump Size (l)	Oil Type	Bypass Centrifuge
DAF 95XF	100,000	17-25	Synthetic ACEA E4	✓
Mercedes Actros	100,000	30-34	Synthetic ACEA E4	✗
MAN 2866	80,000	40	Synthetic ACEA E4	✗
Scania DSC12	45-60,000	35	Mineral ACEA E3	✓
RVI Family 3	30-40,000	32	Mineral ACEA E3	✓
Volvo FH12	30-45,000	35-38	Mineral	✗

Note: Drain Intervals Dependent on Duty Cycle

Figure 2.

TEST RESULTS AND FIELD EXPERIENCE

To further evaluate the possibilities of lube oil contamination control using bypass centrifugal filtration it is necessary to examine data from engine and vehicle tests. In the 1970's and 80's the earlier generation of bypass centrifuges were seen to be effective in reducing engine wear and many tests were conducted to investigate this effect (8,9). In the last 10 years however much development effort has been directed towards controlling oil condition through removing large amounts of carbonaceous material (soot and sludge) and a growing body of test data is now available to illustrate these developments.

Soot & Carbonaceous Material

After the initial oil change when the majority of built-in dirt is removed, carbonaceous material will make up by far the largest proportion of contaminant to be found in the oil of a typical diesel engine. Base soot particles are very small (as mentioned earlier) and modern oils contain powerful dispersants to prevent their agglomeration. The effectiveness of a bypass centrifuge in such a system is shown in Figure 3.

It is evident from Figure 3 that the oil in the engine fitted with the bypass centrifuge contains a far lower level of insolubles at 350 hours (the standard oil drain interval) than the engine fitted with the standard filtration system. Both engines were run under identical conditions however, it was possible to double the oil drain interval in the engine fitted with the centrifuge.

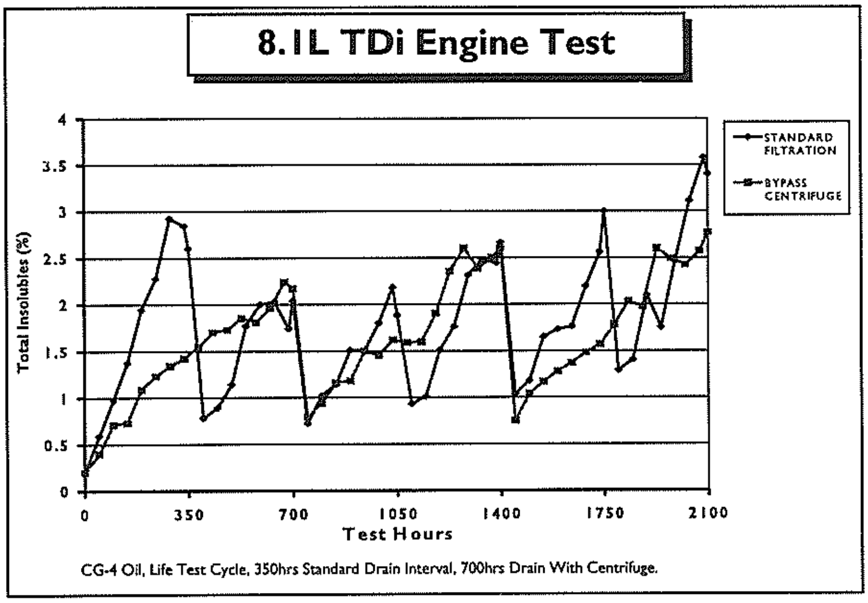

Figure 3.

The long term effects of better contamination control can be seen in the gradients of the curves. For the standard engine the gradients increase as the engine wears.

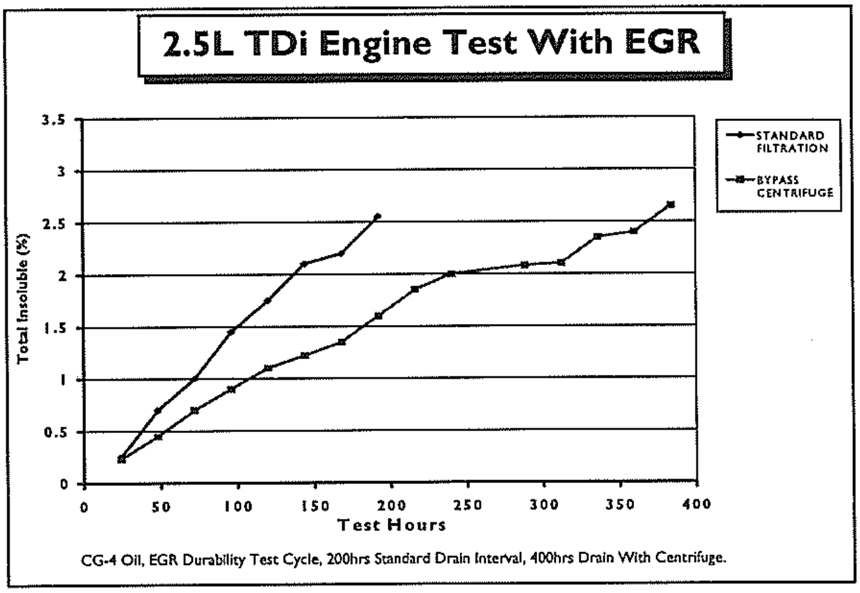

Figure 4.

For the engine with the centrifuge the gradients are similar for the whole test indicating less engine degradation has taken place. This was supported by the condition of the components when the engines were stripped and inspected.

Figure 4 illustrates the effect of fitting a bypass centrifuge to a "low emissions" diesel engine. The test engine had an advanced electronic engine management system, electronic injectors and EGR. The tests were run using a harsh EGR durability cycle of approximately 30% EGR. The goal was to extend the oil drain interval and it can be seen that the engine fitted with the centrifuge took approximately twice as long as the standard engine to reach the same insolubles level (10).

Wear Metals

The control of solid wear debris is essential in assuring maximum durability with new engine designs. Components such as steel or steel/composite pistons and sputter coated bearings have a much lower dirt tolerance than their conventional counterparts, underlining the need to control metals and particulate debris within the lube oil or remove it from the system.

Figure 5 shows the result of fitting a bypass centrifuge to a 5 litre engine on the level of iron observed in the lube oil. This result is from a vehicle test conducted on a city bus running a severe urban duty cycle.

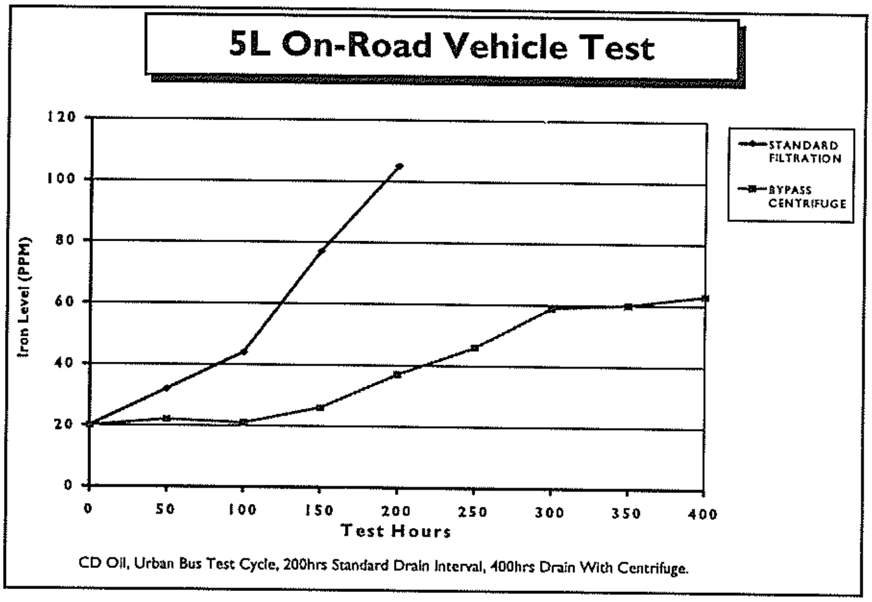

Figure 5.

The dramatic improvement is a typical result and is due in part to the high relative density of iron particles and partly to the reduced rate of particle generation caused by the simultaneous removal of other pro-wear debris from the lube oil.

In Figure 6 one of the results from a series of tests on a smaller engine is shown to illustrate the typical effect that a bypass centrifuge has on the level of aluminium in lube oil samples. The overall levels of metals such as aluminium, copper, lead and tin are normally low in modern engines but it can be seen that there is scope for further reduction.

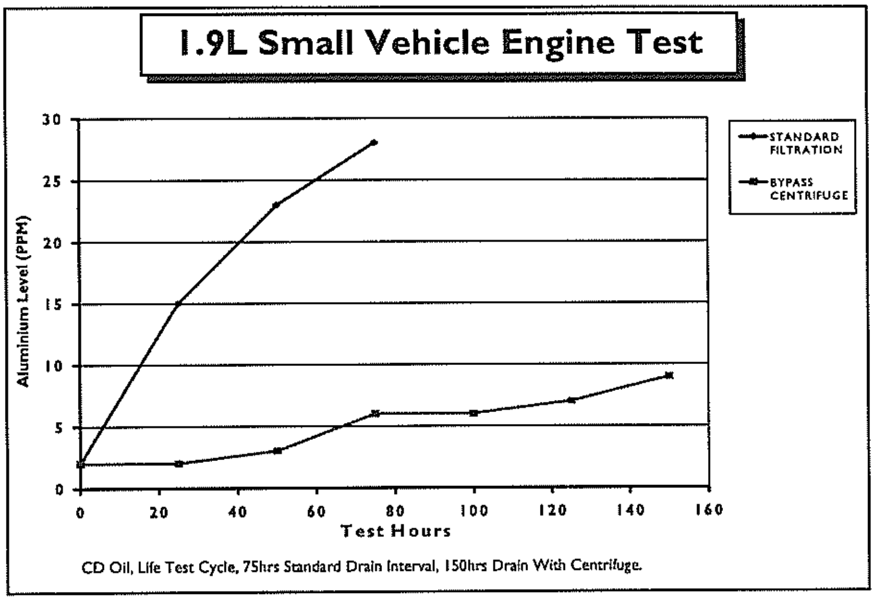

Figure 6.

Viscosity

The control of viscosity increase is one of the key factors required from a modern lube oil system (6). Current CG-4 oils exhibit much better viscosity stability than their predecessors. However, to achieve extended oil drain intervals with future low emission engines it is likely that additional viscosity control measures will be required. The fuel economy benefits conferred by the use of 5W30 oils for example can soon be eroded if the oil's viscosity is allowed to increase significantly over the service interval due to thickening of the oil with high levels of contaminants such as soot.

Figure 7 shows the effect of adding a bypass centrifuge to the rate of viscosity increase of a CG-4 oil in a modern 8.1 *l* diesel engine.

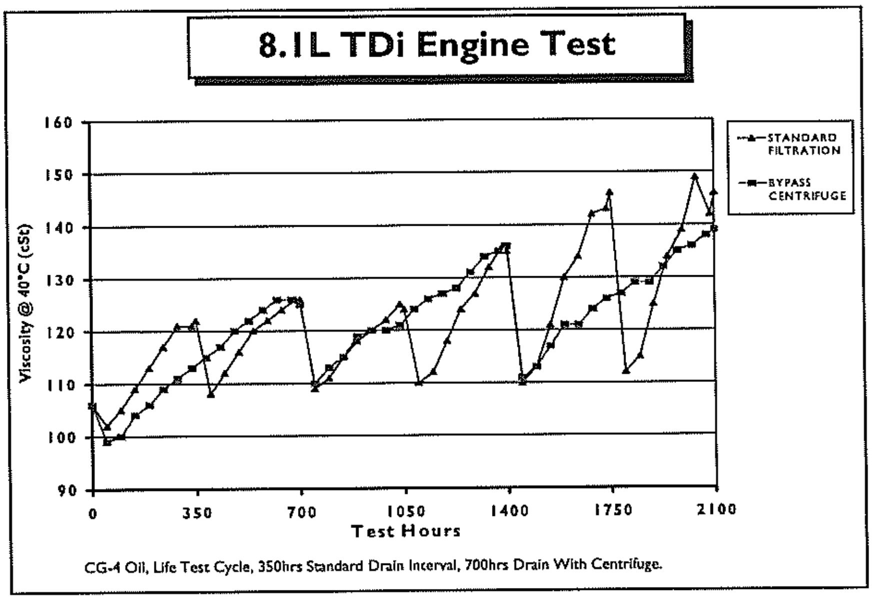

Figure 7.

Once again it can be clearly seen that the a doubling of the oil drain period can be achieved whilst still maintaining a reasonable control of the lube oils viscosity. This being achieved by the removal of soot particles from the lube oil by the bypass centrifugal oil cleaning system.

Additive Package

Modern oils contain substantial amounts of additives and the proportions and relative cost of these compounds are likely to increase with the next generation of lubricants. One of the key parts of a modern oil's additive package is the collection of chemicals designed to prevent products of combustion from agglomerating and settling out on engine components. These are known as dispersants.

Dispersant chemicals work by surrounding particles and isolating them from other similar particles. Dispersant molecules are consumed during engine operation and thus the level of "active" dispersant in an oil will fall over the service life of the oil (11). It can be seen from Figure 8 that the application of an oil cleaning centrifuge reduces the rate at which active dispersancy additives are consumed. This is due to the removal of a significant proportion of the contaminant particles from the oil before they are fully surrounded by dispersant molecules. Reducing the number of dispersant molecules that attach to any one soot particle thus allows better use of the dispersant molecules in an oils additive package hence extending the life of the lube oil.

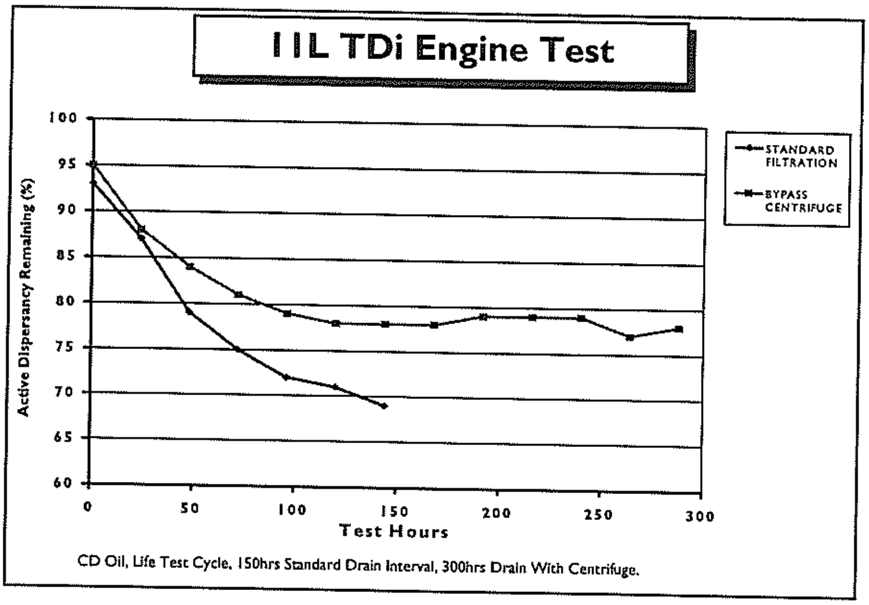

Figure 8.

CONCLUSIONS AND FUTURE TRENDS

In order for even the best current diesel engines to comply with forthcoming emissions legislation it is clear that a wide range of design changes will be required. Many of these changes, whilst effective at reducing tailpipe emissions, may have penalties in terms of oil cleanliness. These changes will be taking place in a

marketplace that is demanding lower oil consumption (and therefore less top-up) and longer drain intervals.
The lubricating oil in these new engines will be placed under enormous strain and it now appears unlikely that all the demands on the lube system can be met by high-tech oils using only standard barrier filtration techniques.

Many manufacturers have already started looking at advances in filtration systems. Several German manufacturers for example have moved towards totally incinerable filter units to reduce the burden on the environment, some have taken the opportunity to enlarge the size of the filter at the same time (no doubt with extended drain intervals and increased dirt holding capacity in mind). These are only partial solutions however. To make a real step forward will require a different approach to filtration.

The bypass centrifugal oil cleaning system has been shown to contribute greatly to maintaining oil condition over extended drain intervals. Examining the system more closely however it is possible to discover a number of other benefits. Bypass centrifuges can be fitted in combination with long life or fit-for-life metal mesh full flow screens in place of traditional barrier filters. This means that a fully cleanable filtration system is possible where the only waste to be disposed of is the contaminant itself (mainly soot). And since the action of a centrifuge compacts this contaminant into a hard cake it is easy to handle and contains very little residual oil. Disposable centrifuge rotors are also available where the unit can (in most cases) be recycled as scrap steel, the contaminant inside being burnt off in the smelting process. The use of centrifugal oil cleaning systems on small engines will bring the goal of "sealed for life" lubrication one step closer.

It is envisaged that the next generation of diesel engines which need to be Euro IV compliant will burn very little oil, will have small sumps, will have smooth, faceted blocks for noise attenuation and for the most part will incorporate a bypass centrifugal oil cleaning system. The development of the compact, highly efficient centrifuge systems which will be required to meet these demands is already well underway. It can also be seen that with the current climate of reducing engine component counts it is likely that future engines will use more integrated lubrication systems with perhaps a high efficiency oil pump, a full flow metal screen, an integral lube oil heat exchanger and high efficiency centrifuge all incorporated in a single housing, a "Lubricant Conditioning Unit" which an engine manufacturer would simply design on to the engine.

Engine designers who do not take up the challenge of lube oil contamination control for their new engines will not only find it difficult to meet the challenge of Euro IV but will find it increasingly more difficult to meet future regulations in these times of high environmental awareness.

REFERENCES

1. Bunting, A., "Squeezing Diesel Emissions", Truck Magazine, pp 26-27, January 1997.
2. "Drains Strains and Fuel Gains", Truck Magazine, pp 44-47, June 1997.
3. Kawamura, M., Ishiguro, T., Moromito, H., "Electron Microscopic Observation of Soots in Used Diesel Engine Oils", Lubrication Engineering, V34,7, pp 572-575, 1987.
4. Constans, B., Bezot, P., Hesse-Bezot, C., "Laser Particle Sizing of Diesel Soots in Two Formulated Oils After Different Engine Tests", Tribotest Journal 1-2, pp 125-146, 1994.
5. Sun, R., Kittleson, D.B., Blackshear, P.L., "Size Distribution of Diesel Soot in the Lubricating Oil", SAE paper No. 912344.
6. Bardasz, E.A., Cowling, S.V., Ebeling, V.L., George, H.F., Graf, M.M., Kornbrekke, R.E., Ripple, D.E., "Understanding Soot Mediated Oil Thickening Through Designed Experimentation - Part 1: Mack EM6-287, GM 6 2L", SAE Fuels & Lubricants Meeting & Exposition, Toronto, Ontario, 16-19 October 1995, SAE paper No. 952527.
7. Miyahara, M., Watanabe, Y., Naitoh, M., Hosonuma, K., Tamura, K., "Investigation into Extending Diesel Engine Oil Drain Interval (Part 1) - Oil Drain Interval Extension by Increasing Efficiency of Filtering Soot in Lubricating Oil", SAE paper No. 912339.
8. Graham, N.A., "By-Pass Lube Oil Filtration", International Congress and Exposition, Detroit, Michigan, 24-28 February 1986, SAE paper No. 860547.
9. McNair, J., "Comparison Between Different Bypass Lubricating Oil Cleaning Systems", SAE paper No. 930996.
10. Backhouse, M.E., Purcell, D.C., "Cleaning of Lubricating Oil - The Needs of the Future", T&N Symposium, Würzburg & Indianapolis, paper No. 5, 1995.
11. McGreehan, J.A., Rynbrandt, J.D., Hansel, T.J., "Effect of Oil Formulations in Minimizing Viscosity Increase and Sludge Due to Diesel Engine Soot", SAE paper No. 841370.