Engine Lube Oil Contaminants
Using Solids Collected by Oil Cleaning Centrifuge to Assess Size and Composition
(#92-O-2)

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INTRODUCTION

The motor-driven centrifuge has been applied for many years on high horsepower, low-speed marine diesels to provide clean, debris-free fuel and to control wear and combustion contaminants in the engine lubricating system. More recent versions, using the pressure of the lube circuit to self-power a high-speed centrifuge turbine, have been widely applied in North America and Europe to clean lube oil in engines applied to heavy-duty trucks, buses, and electrical gen sets; more recently, these same centrifuges have been installed on pipeline compressor engines.

Current legislation limiting the inexpensive landfill disposal of used lube oil filter elements has focused attention on alternative strategies for maintaining the cleanliness of engine lube oil. One such strategy is to match the bypass cleaning function of the centrifuge with a full-flow cleanable screen lube filter (see Figure 1). This system has proven capable of achieving effective contaminant control in an arrangement that can be completely cleaned by the user: the majority of the debris mass is collected inside the bypass centrifuge (which is hand-cleanable) while the full-flow screen, when differential pressure exceeds pre-set limits, can be ultrasonically cleaned or jet-spray washed in water.

In the centrifuge/screen filtration system, the traditional full-flow filter is replaced with a cleanable stainless steel screen of suitable size and rating; the function is to provide large size debris-trapping protection for all the lubricated engine components. The centrifuge is a bypass filtration device, capable of removing very fine particulate (less than 1 µm in size), but is driven by only a fraction (approximately 10%) of the total lubricating oil flow in the engine. Oil from the centrifuge is returned to the crankcase. These components operate together as a system to provide significantly improved contaminant control than would otherwise be possible if traditional disposable filter elements alone were applied.

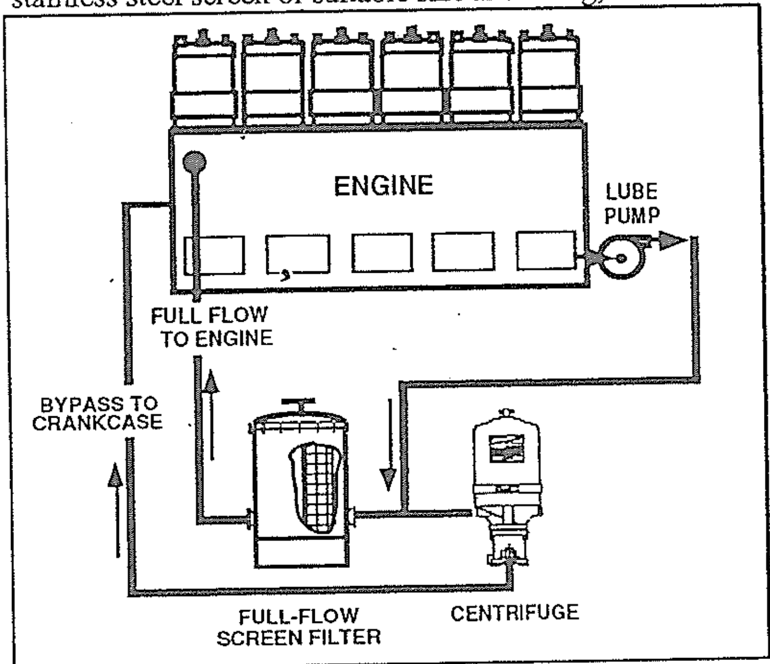


Figure 1— Centrifuge/Screen Filtration System

Because the gas transmission pipeline market was among the first group of engine users to be impacted by disposal limits on used lube filters, trials on the centrifuge and centrifuge/screen systems were begun on natural gas-fired integral compressor engines. A field data collection effort has now been completed, providing details on the performance of the lube pressure-powered centrifuge, plus data on installations where a screen full-flow filter has also been applied. Three methods of qualitative and quantitative assessment of lube oil contaminants were applied and are reported in this paper:

1 - Physical chemistry of the solids collected in the centrifuge bowl to objectively identify the various debris constituents in the used lube oil not removed by standard full-flow lube oil filtration.

2 - Particle counts of the centrifuged solids using specialized electrostatic methods, providing distribution of all contaminants by size.

3 - Particle counts of used lube oil on centrifuge and full-flow screen-equipped engines by means of two counting methods.
4 - Ferrographic analysis with photomicrographs of the wear debris.

OIL CLEANING CENTRIFUGE — BRIEF BACKGROUND

The oil cleaning centrifuge is a dynamic means of removing harmful abrasives from engine lube oil. As originally conceived, the oil pressure-powered centrifuge allowed centrifugal separation to be applied first on diesels smaller and less costly than those used in ocean-going marine service (1). Centrifuges have been used on large ships for over 50 years, typically powered by high-speed electric motors.

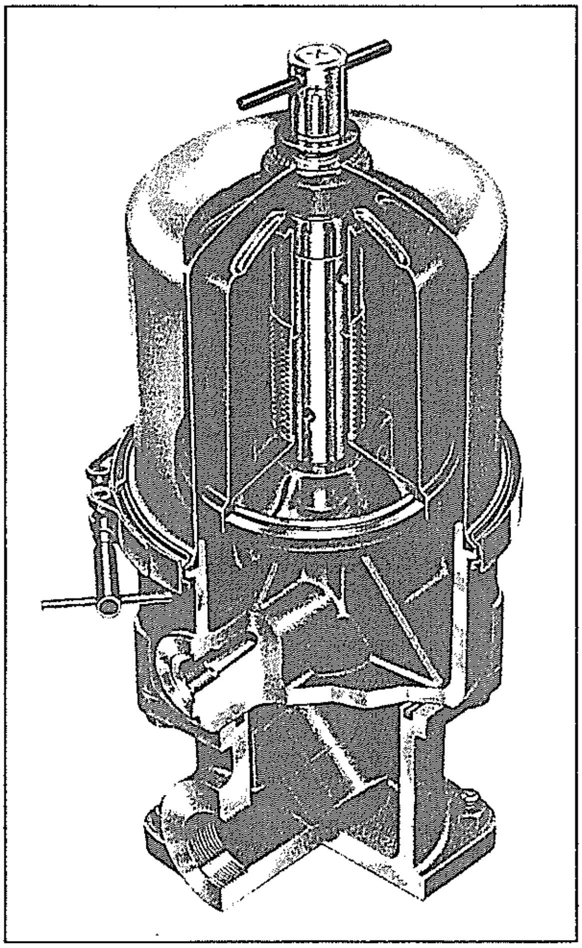


Figure 2— Oil Cleaning Centrifuge for Large Engines

The centrifuge design studied in this report is a product with oil flows ranging from 4 to 120 lpm typically applied to engines with swept displacements of 3 to 500 liters and larger. In its simplest and a somewhat smaller form, the engine-powered centrifuge is currently applied on over 300,000 Saab-Scania truck and marine diesels. Other manufacturers applying the larger form of this oil pressure-powered centrifuge include Alsthom Atlantique, British Polar, Daihatsu, Fuji, K.H.D., Mirrlees Blackstone, Mitsubishi, Ruston, Wartsila and Yanmar. In many applications, the basic centrifuge is augmented by the addition of the Level Control Base as an oil sump (2), allowing the unit to be reliably remote-mounted (see Figure 2). Over 80,000 units of this smaller version have been installed in North America, principally on line-haul truck applications.

While the centrifuge is most often applied only to *complement* the contaminant control capability of the full-flow lube filter on engines, there is a 25-year production history of durable high-speed diesels with no other lube oil contaminant control device than a cleanable centrifuge (Saab-Scania).

CENTRIFUGE OPERATION

The remote or engine-mounted centrifuge is used as a bypass filtration device, cleansing a fraction of the total oil flow supplied for engine lubrication and returning that fraction to the engine lube sump. Its operation is relatively simple:

1 - High pressure engine lube oil flows into the centrifuge turbine assembly through passages that feed the rifle-drilled turbine spindle.
2 - This pressure & flow is converted into rotational energy as the oil escapes through the turbine jets, producing speeds in excess of 3500 RPM (and higher on smaller units).

3 - Forces on the oil in the rotating centrifuge exceed 1000 times that of gravity. This slams dirt and wear debris against the side wall of the turbine, where it collects in a hard, black mass.
4 - Centrifugally-cleaned oil drains into the Level Control Base sump, where an automatic air system provides a "boost" of force to assist in returning the oil back to the diesel crankcase through small hoses. The unit may be gravity-drained in arrangements mounted directly onto a engine crankcase door.

CENTRIFUGE EFFECTS ON ENGINE LIFE

Laboratory tests of the performance of the oil cleaning centrifuge with wear rate accelerated by use of naturally-occuring abrasives has proven its ability to cost-effectively control the very contaminants that cause attritional wear of close-tolerance engine component operating surfaces (3, 5). Extensive lab testing by high and medium speed engine manufacturers has shown that smaller contaminant sizes in the 0 to 10μm range have the greatest detrimental impact on ring and bearing life, and must be controlled to achieve longer component life and to maintain peak performance.

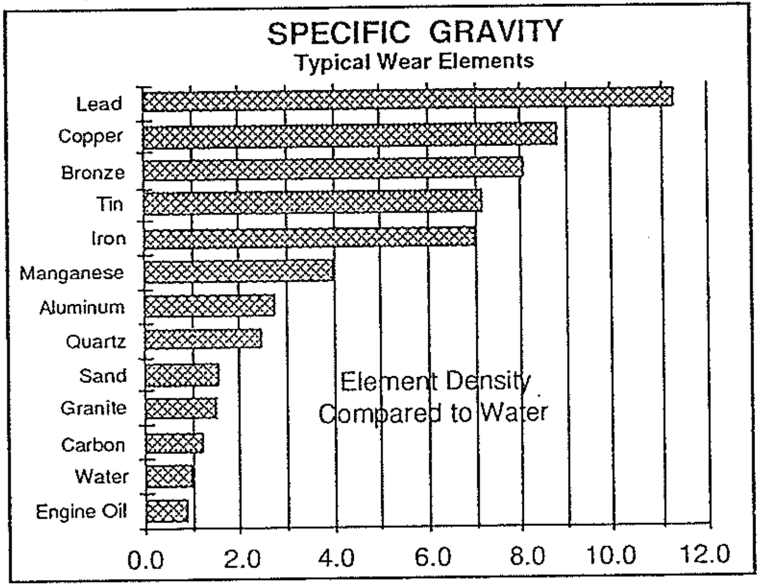


Figure 3 — Density of Typical Wear Metals

With a Spinner II Oil Cleaning Centrifuge, the harmful wear 'metals and abrasives in an engine are continually being removed from the lube oil by action of the 1000 g's of force. Some of the most abrasive contaminants are the heaviest (highest density, Figure 3), and are more quickly removed by centrifugal force than the lighter components (like carbon). However, since effectiveness of the centrifuge is nearly constant over all of the lube service cycle, rather than decreasing as with other means of bypass cleaning, large amounts of contaminants across a wide range of density and to a very small size are removed, reducing engine component wear dramatically.

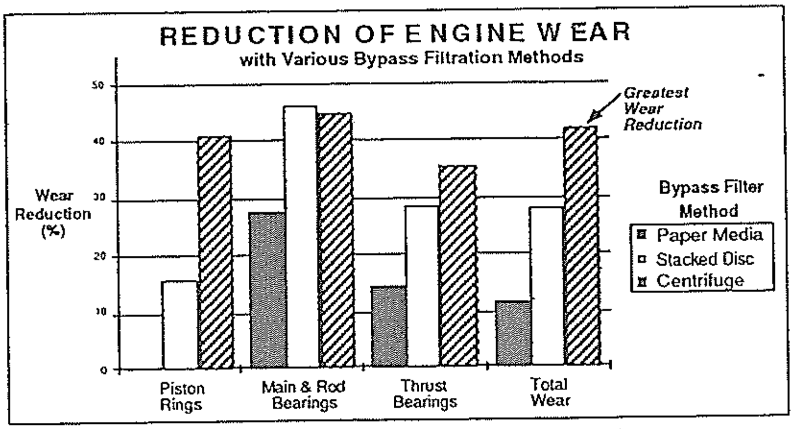


Figure 4 — Accelerated Wear Test on High Speed Diesel

Since the centrifuge removes contaminant on the basis of density and not on size, the heavier, more abrasive debris (including the very small ones) is removed rapidly and at continuously high rates; the centrifuge is not subject to the ever-decreasing flowrate that occurs in a bypass filter as the filter medium becomes clogged with dirt. As a result, in accelerated wear lab tests as graphed in Figure 4, the engine equipped with a centrifuge had substantially less overall wear on components than did alternative bypass filter approaches.

CONTAMINANT ASSESSMENT METHODS

In the last decade, engine manufacturers have achieved extended component durability through design improvements, application of better methods of lube oil filtration (6,7) and better lube oil formulation. During this time, the technicians helping to evaluate alternatives in filtration system design found the traditional "oil analysis" methods applied by maintenance managers inadequate to the task of providing a real-time check on what these filter systems were accomplishing; their power at discriminating variations in contaminant control was just too limited (8,9).

Filter performance test methods provide objective means to compare full-flow media-type filters in a bench test setting, but are not intended to assess field performance (10). As a result, users and service personnel developed assessment methods that do offer ways to identify performance of lube oil filtration sytems as they operate in field environments. Four of these methods have been employed to provide assessment of centrifuges and centrifuge/screen filtration systems applied to operating engines. They are:

1 - Physical chemistry of centrifuged solids
2 - Analysis of Ferrographic deposits
3 - Particle counts of centrifuged solids
4 - Particle counts of used lube oil.

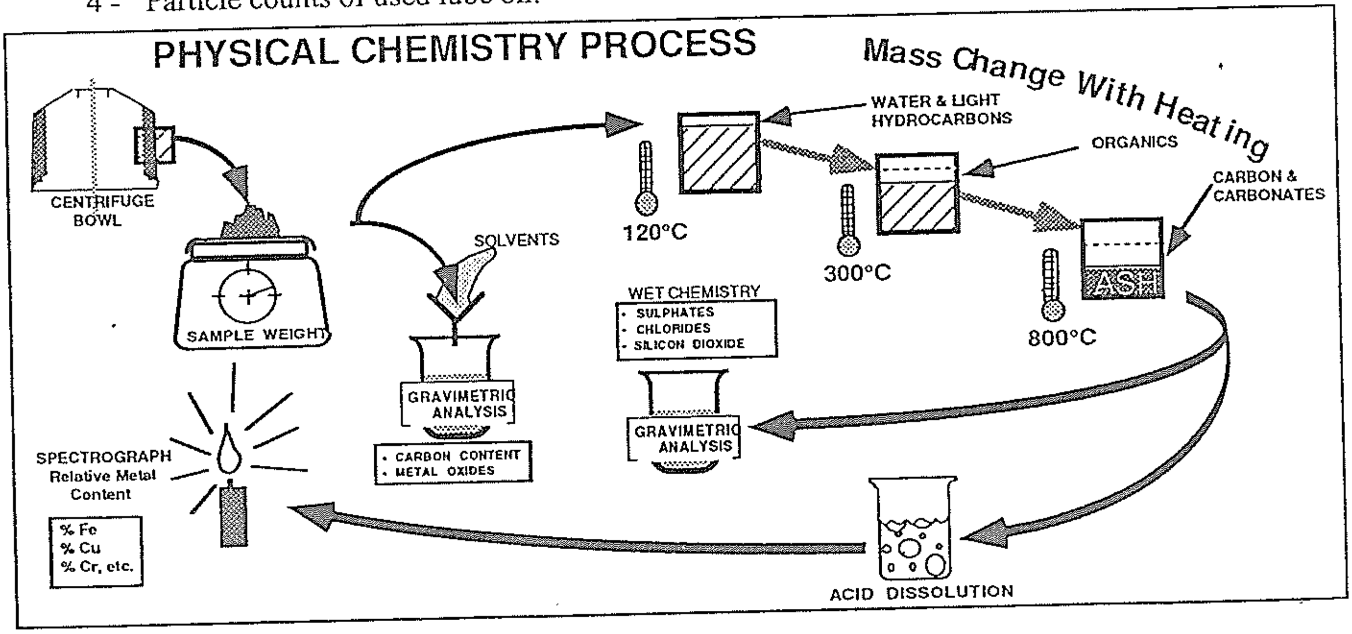


Figure 5— Centrifuge Solids Physical Chemistry Process

PHYSICAL CHEMISTRY OF CENTRIFUGED SOLIDS

The full value of chemical dissection of the centrifuged solids has been realized recently after a complete and staged sequence was devised to break the solid into its debris constituents. The basic process is outlined above in Figure 5. The process identifies specific elemental constituents present as wear debris by use of solvency, chemical titration, thermo-gravimetric analysis (11), then adds a spectrographic survey only after acids have been applied to the ashed sample to ensure complete methods, there is an overlap in the carbon reading, indicating that lab test methods still are subject to variations of accuracy; the total carbon reading is typically given credence.

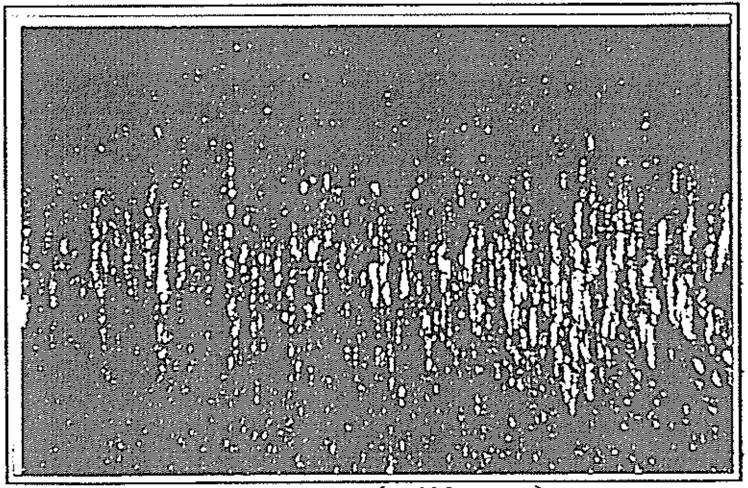
The centrifuged solids contaminant with the greatest interest to most customers are the wear debris and metallics. Traditional, low-cost oil analysis routinely conducted by engine users throughout North America is a process that includes a series of checks on the condition of the oil, and its fitness for continued service, plus some sort of quantification of metals in the oil by spectrography. This spectrographic analysis is conducted by a number of different methods, all related by the common detail of heating the sample to a high enough temperature so that the suspended elements will create or absorb an emission that can be reliably related to that specific element. It has the unfortunate limitation of poor accuracy with contaminants in size ranges that can typically be controlled by barrier and centrifugal filtration methods (9). As a result, it cannot be reliably used as a method of comparing the merits of alternative filtration strategies.

Wear Element	Fraction	Mass
Iron	1.44 %	35014 mg
Lead	0.05 %	1216 mg
Copper	0.24 %	5836 mg
Chromium	0.08 %	1945 mg
Aluminum	0.03 %	729 mg
Nickel	0.02 %	486 mg
Tin	0.00 %	0 mg
Silicon	0.08 %	1943 mg

Table 1 - Mass Fraction, by Metal Oxide Element Collected in Centrifuge Applied to Integral Compressor Lube System

With this in mind, a physical chemistry process was devised to take advantage of the "information" contained in the centrifuge deposits, which represent a "history" of recent debris present in a diesel's lube circuit. The work sponsored by the U.S. Air Force at Wright-Patterson AFB indicated that spectrographic accuracies could be greatly enhanced by exposing the sample to acid dissolution (sometimes known as acid digestion), chemically breaking down the wear debris to a size that could be repeatedly and reliably aspirated into and completely "burned" by the spectrographic process. This is precisely the approach followed in the physical chemistry of centrifuged solids from the engines described above, and the result is a variable identified collectively as metal oxides or "ASH" on the diagram of Figure 5.

The metal oxides are the most obnoxious components in the centrifuged solids, since they include the hard abrasives of internally-generated wear debris, combustion debris and ingressed contaminants like sand. This debris creates a major fraction of the wear occuring in engine rings, cams, and bearings.


(Photomicrograph at 100x ←400 µm→)
Photo 2 - Ferrogram® of Compressor Engine Lube Contaminants

This contaminant review method could be used for field assessment of design or operational variables and the resultant effect on component wear, but this has not yet been done in a controlled manner on a *single* engine. Rather what is available is a "snapshot" of all those studied, indicating in each case that the centrifuge is capable of removing substantial contaminant mass from the engine lube system. The mass of collected metal oxides varies according to the condition of the engine, and will intitially, at first application, be higher until the engine, operating surfaces and crankcase "unload" dirt. In this case, the 11.3 kg (25.1 lbs) of collected contaminant was found to be composed of 21.6% metal oxides, or 2431 grams.

metals breakdown for analysis. Ferrographic slides are prepared and photomicrographs taken of selected slide locations over a range of magnifications and background light conditions.

A physical chemistry on the solids collected from centrifuges operating on an Ingersoll-Rand 12TVR Integral Compressor gas-fired engine has been completed through application of this process (12). A summary of the mass and solvent chemistry data is shown in Table 1 above.

Centrifuged solids from many engine lube systems typically have a black, grainy appearance with carbon, soot, wear debris, unburnt fuel components, spent lube additives and combustion products bound into a homogenized, rubbery matrix. During operation, centrifugal force separates this debris from the lube oil, depositing it in an increasing annulus on the inside of the turbine bowl; the debris adheres to itself bound by the degradation products of the oil. Photo 1 shows an example of the mass and appearance of debris collected from the lube system a large engine fueled with pipeline grade natural gas. Over 11.4 kg (25 pounds) of contaminant was centrifuged from this engine oil sump in the first 704 hours of operation.

Constituent	Fraction	Weight
Total Sample	100.0 %	11278.0 grams
Total Carbon	48.9 %	5514.0 grams
Retained Water / Light HC's	2.7 %	309.0 grams
Volatile Organics	34.4 %	3878.5 grams
Oxidizable Fraction (Carbon & Carbonates)	41.3 %	4659.0 grams
Residual Ash	21.6 %	2431.5 grams

Table 1 — Mass & Solvent Chemistry Results

While carbon and soot are the least dense of the oil contaminants (specific gravity ranging from 1.2 to 1.8), they represent the largest fraction, by mass, of the centrifuged solids. Pure carbon results from incomplete combustion of fuel and soot be described as combustion products adhering to a carbon core (13,14,15). In the compressor engine, the carbon/soot fraction was 49.8% of the total mass of collected debris (5.7 kg). The large mass at this service point was collected soon after the centrifuge was first installed; crankcase clean-up continued for many hours past this point; for example, *total* solids mass at a further 812 service hours was 9.7 kg (21.3 lbs).

The carbon fraction, interacting with combustion products, deposits on operating surfaces (reducing engine performance) and has been shown to diminish the capability of engine lube oil anti-wear additives (13).

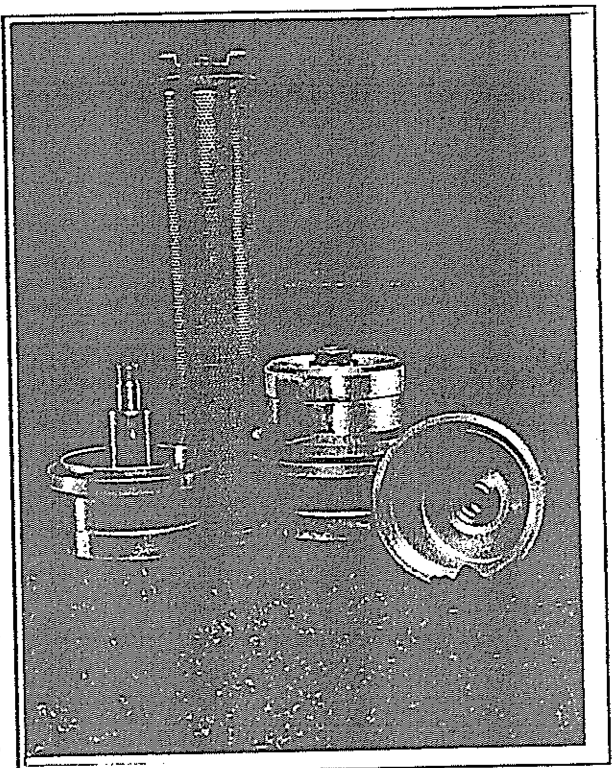


Photo 1 - Lube Oil Contaminants Collected by Oil-Powered Centrifuges; Pipeline Integral Compressor

The second analytical method employed in this physical chemistry process is observation of mass changes occuring while heating of the sample (please refer to Figure 5) Each upward temperature excursion decreases mass of the centrifuge solids because of chemical changes; these changes identify the fractions attributable to water, organics and oxidizable fraction. What's left is an ash which then can be prepared for elemental analysis of metals. As can be seen in the comparison of the two

Table 1 above shows a summary of elemental wear masses, by percentage of total metal oxides, collected in the test engine centrifuges over the first 704 hour operating interval. Two comments can be made on this analysis that indicate the practical utility of a *complete* physical chemistry of collected centrifuge wear debris:

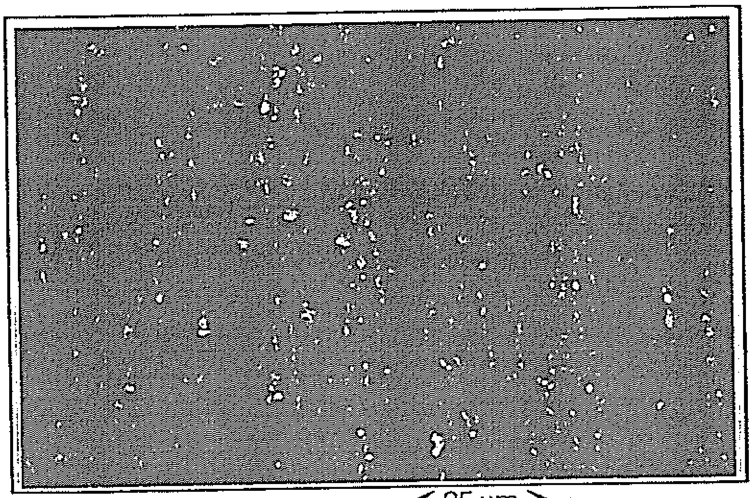
1 - This review of the debris collected from the IR 12 TVR engine showed no trace of tin; the manufacturer has confirmed that this engine design includes no components with tin wear surfaces.

2 - Some constituents cannot be completely analyzed through conventional spectrographic techniques, but can be segregated through sequential exposure to other solutions. An example is from this set of data where silicon is detected:

Analysis Method	Total Mass
Spectrographic Si O_2	1943 mg
Gravimetric Si O_2	24315 mg

Silicon levels detected by this sequential solution technique are *additional* to that indicated by spectrography, another indication that spectrographic analysis, even when *augmented* by acid dissolution, is unable to detect all of the abrasive wear metals present in the sample.

Other metallic oxides, analyzed but not reported above, include those associated with the lube oil additive package. Spent additives are removed by any filter system capable of effective contaminant control, since the additives become attached to carbon soot particles and wear debris. In this attachment, anti-wear (for example, Zinc Di-thiophosphate) and other additives are simply fulfilling their designed task, which is to prevent the contaminants from adversely affecting the lubricating benefits of the oil and keep them away from engine wear surfaces (16). Extensive testing has shown that the oil cleaning centrifuge described in this paper does not remove *active* additives from the engine lube oil.



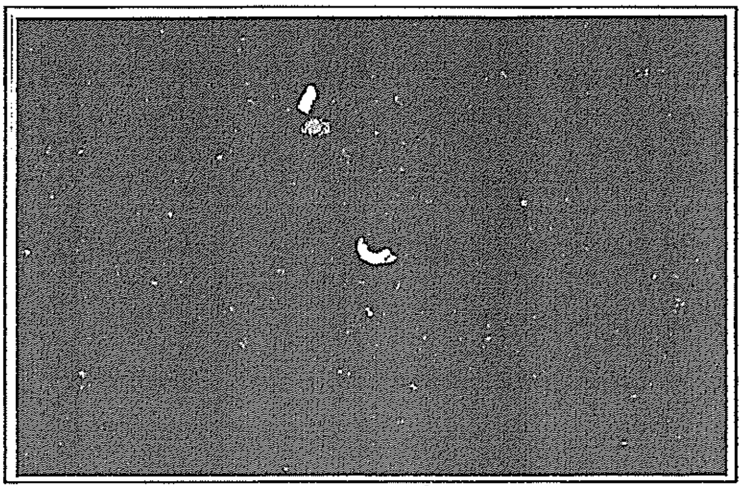
(Photomicrograph at 1000x ≪25 µm≫)

Photo 3 - Ferrogram of Compressor Engine Lube Wear Debris

FERROGRAPHIC ANALYSIS OF CENTRIFUGED SOLIDS

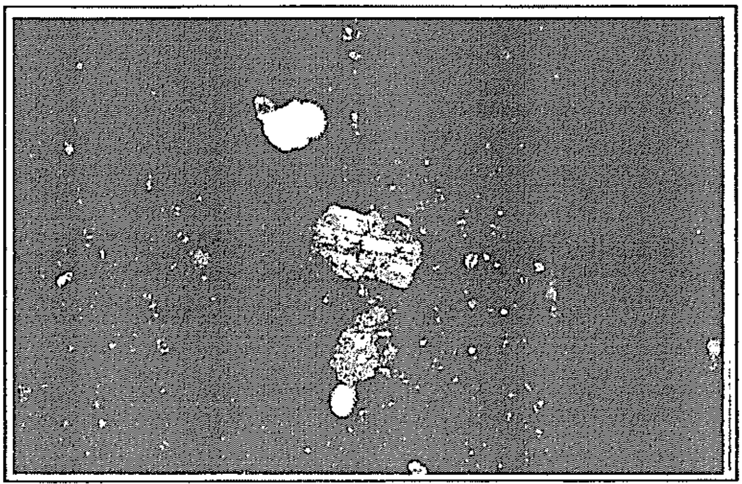
The Ferrograph® is a device which segregates wear materials from a lube oil by use of the forces of magnetism and gravity. Contaminated oil traverses a glass slide which is suspended at an angle over a magnetic field. Ferromagnetic wear materials deposit along the slide's length, dragging with them other non-magentic debris and these can be observed through a microscope. Ferrographic analysis can reveal wear particle concentration, their size distribution and morphology (shape); elemental analysis of the constituents is done on the basis of appearance and by using comparison against a photographic lexicon of known contaminants. These traits are indicative of the type and severity of wear occuring in lubricated equipment. Photomicrographs of all or parts of these slides can be taken at varying magnifications.

Because Ferrography relies largely on magnetic forces to separate metal particles, when traditional oil samples are analyzed, iron particles are the most often detected (separated) wear materials deposited on the slide. The oil cleaning centrifuge is itself a wear debris concentrator, so as a result, the distribution of material on these slides is heavily weighted toward wear metals, making the Ferrographic process particularly useful in wear trends analysis on systems where centrifuges are applied.



(Photomicrograph at 1000x ←25 µm→)
Photo 4 - Ferrogram of Compressor Engine Lube Wear Debris

Photo 2 shows a photograph of the entire Ferrogram® slide, at 100x magnification on a sample from the 4-cycle integral compressor engine. The magnetic field tends to 'bunch up' the large particles at the leading end of the slide, and make finer and progressively less concentrated deposits toward the end of the slide. This frame shows the raw sediment clumped up in groups agglomerated around carbon particles; the sediment has been backlighted by the microscope lamp. The heavily ferromagnetic content in the debris cause the noticeable repetitive parallel alignment of the dirt in windrows. Gaps between the windrows are areas of light or no sample deposit. Zooming in on this frame to higher magnification allows the analyst to observe individual wear debris. A series of photomicrographs like photo 2 has been included in this report; although the color of the original slides is a critical cue toward making an accurate analysis, the black & white versions provide a hint of the details.



(Photomicrograph at 1000x ←25 µm→)
Photo 5 - Ferrogram of Gas-fueled Engine Lube Wear Debris

Photo 3 above shows another slide of the sample from the IR integral compressor. At this 1000x magnification, details of the "debris windrows" are very clear: in this case, analysts identified the presence of silicon particles randomly laid over windrowed ferrous wear debris, and carbon in the background. The Ferrogram shown in Photo 4 was also magnified at 1000x and shows an abrasion cutting wear particle approximately 8µm in size.

The Ferrogram to the left (Photo 5) was photgraphed at 1000x magnification. It displays two 12 and 22µm copper abrasion wear particles of a centrifuged solids sample from a small gas-fired Waukesha engine used to drive a gas-gathering system. (A full report on this debris analysis is available, reference 17)

Repeated below is a set of comments after debris analysis was completed on two different gas-fueled engines equipped with lube oil centrifuges; this Ferrographic analysis identified:

- Fibers ranging from 80 to 170 µm were observed; they may represent full-flow media migration

- One sample showed a bearing babbitt particle, 116µm in size; this was retrieved from the engine which has full-flow filtration rated by the manufacturer at $\beta_{28} = 75$ (approximately 28µm absolute). If photo 2, above, is studied closely, this babbitt "chunk" can be observed in the right central part of the frame. The presense of a piece of debris this large, trapped by the centrifuge, points out the benefit of effective bypass filtration to complement the full-flow filter.
- Lead alloy particles in the 5 to 8 µm size range are present. The presense of a piece of debris this large, trapped by the centrifuge, points out the benefit of effective bypass filtration to complement the full-flow filter.
- Normal ferrous rubbing wear particles, 5 to 9 µm size range were common.
- Other wear debris, like copper particles (10 to 20 µm) from sleeve bearings are present.
- Sand was evident in all samples. Sand is ingressed principally through the engine air intake, and has to be controlled by lube filtration to provide long component life. Other sand sources are engine block castings which release quite a lot of material during break-in.

PARTICLE COUNTS OF CENTRIFUGED SOLIDS

As interest and application of the oil cleaning centrifuge for on and off-road installations has grown, its been accompanied by the inevitable question, "Just how small a particle does this device remove?". Most engineers who study contaminant control prefer not to respond directly to such an inquiry, knowing how this one fact alone does not constitute a meaningful performance measure for a filter's ability to do its job. When allowed alternate means to describe how effectively a filter or filter system can trap debris, most will rely on well-established test methods like the Multi-pass Filter Efficiency Test Method (10). This approach is designed for barrier filters whose characteristic performance trait, ΔP (differential pressure across the filter during fluid flow), gradually increases with entrapment of debris. While this test method has been modified and applied to the centrifuge (18), the fact that the debris is deposited inside a centrifuge bowl and accessible offers a unique ability to easily examine and analyze collected debris, which is difficult or impossible to do with barrier filters.

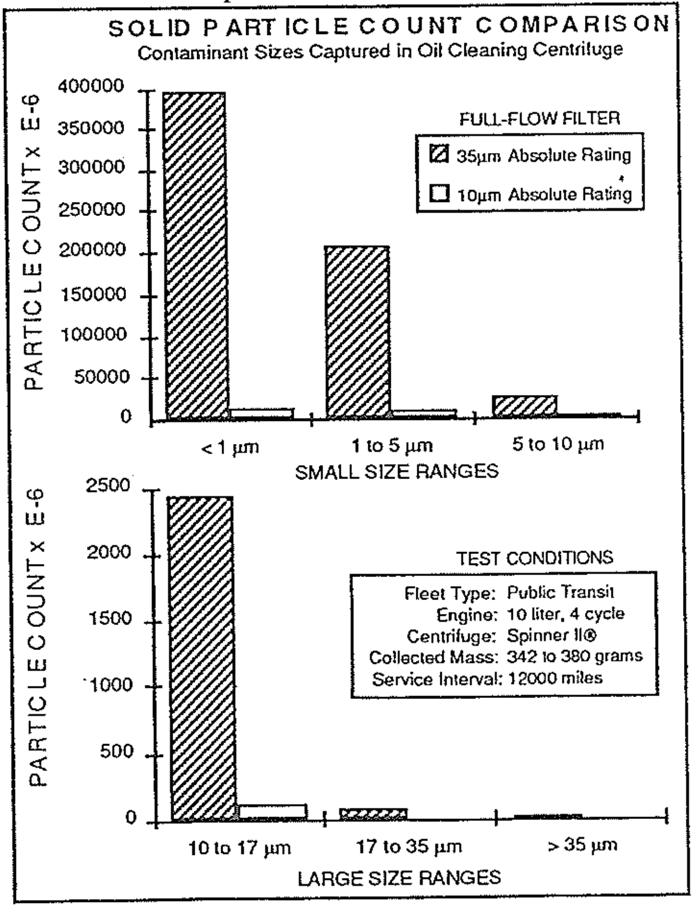


Figure 6 - Solid Particle Counts of Centrifuged Solids

With this in mind, a company capable of providing a particle size and distribution analysis on solid debris was identified. The test approach was to identify a single engine, install a centrifuge, collect contaminant, and particle-count this collected debris. Since the customer has an abiding interest in employing high-efficiency full-flow lube filters along with the bypass oil cleaning centrifuge, we agreed to explore the influence of the full-flow filter performance rating on the size distribution of the collected centrifuge debris.

Centrifuge samples were retrieved from an otherwise normally-operating bus; the first sample was retrieved after operation with the 10μm full-flow and the second, after the 35μm ($ß_{35} = 75$) full-flow had traversed its normal service interval. These two bowl samples were analyzed and the results have been graphed above in Figure 6.

Its quite clear from the data that the field performance of these two full-flow filters reflects their own multipass rating well, since particle counts for each fall to low levels above the characteristic removal size. Most interesting in either case is that the mass of debris removed by the oil cleaning centrifuge remains nearly the *same* for each test case. It appears that the dirt size population distinguishing the two cases is still a relatively small portion of the total contaminant volume left uncontrolled by the full-flow filters.

The bowl solids are a valuable source of relevant engine "dirt" for use in defining physical traits (physical chemistry), particle morphology (Ferrograph) or solid contaminant size distribution.

PARTICLE COUNTING OF USED INTEGRAL COMPRESSOR LUBE OILS

While most of the methods for analyzing the effects of centrifuges and filtration strategies have been developed in the diesel marketplace, they are none-the-less useful for gas-fueled engines. The physical chemistries cited above, and the solids size distributions completed on centrifuged solids have confirmed the amount and nature of the abrasive wear debris removed from engine lube oils during operation. However, at the beginning of this test series for the compressor pipeline market, a real-time assessment of the centrifuge effects on the lube oil itself was made an objective. There are two methods now in use at various analytical labs for contaminant particle counting of lube oils where the wear debris in the oil is occluded by the presence of fine, very dark carbon and soot. The two methods are briefly described in Table 2.

Counting Method	Type of Analysis	General Description
Sample Re-Suspension	Optical	Pre-filter used engine lube sample through 5μm sized Nucleopore® filter paper to exclude carbon/soot population from the sample; ultrasonically re-suspend remaining sample into a counting fluid and perform traditional automatic optical particle count
Coulter LCM II®	Screen Occlusion	The lube oil sample is pumped through three separate stainless wire mesh screens of different ratings; differential pressure on each screen increases as dirt accumulates on each screen. The rate of this increase is compared through the use of a computer model to a known contaminant distribution, providing a derived sample count and distribution.

Table 2 - Engine Lube Oil Particle Counts Methods

Re-SUSPENSION METHOD OF PARTICLE COUNTING

One integral compressor installation studied employed a twin centrifuge arrangement, retaining the standard paper media full-flow element style lube oil filtration ($ß_{28} = 75$). The engine, an Ingersoll-Rand 12TVR, is used for gas compression at an underground storage facility in Texas. With the two large centrifuges rated for a total 32 gpm at 60 psi, the engine oil sump volume is processed 7.5x per hour through the centrifuges, which as shown in Figure 1, operate in a bypass loop mode. Both lube oil samples and centrifuged solids were collected throughout the test; the physical chemistry data already cited was conducted on sample #5 as shown in Table 3, oil sample particle count analysis was conducted by means of the sample re-suspension method.

Sample	Counts > 5μm	Counts > 15μm	Mass Collected	Engine Hrs.	Hrs.on Centrifuge
(oil)1	19767	5390	-	0	0
(oil)2	249980	25710	-	57	0
(solids)3			6.9 lbs.	137	80
(oil)4	164500	4950	-	396	210
(solids)5			25.1 lbs.	841	784
(oil)6	159490	6780	-	964	778
(solids)7			21.4 lbs.	1702	1516
(oil)8	27242	1784	-	1702	1516

Table 3 - Used Lube Oil Particle Counts from Integral Compressor Engine Using Re-Suspension Method

Table 3 shows the contaminant-reducing ability of the centrifuge in clear numerical form. The initial sample, number 1, is representative of the condition of the engine when it is not operating, due to the demand for gas delivery, so there is no storage taking place. Once the engine begins operating on a more consistent basis, the particle count population increases by an order of magnitude, as seen in sample 2. As the lube-powered centrifuge operates, and continues to cycle the system volume and remove dirt, large amounts of debris are removed; this is not only likely to come from the lube oil, but also off of engine surfaces plated with material.

By 1500 hours of operation, the centrifuges had removed in excess of 50 pounds of contaminant, and the particle count of the lube oil is comparable to a non-operating state, before the engine was in continuous use. The centrifuge has the ability to provide significantly cleaner lube oil than traditional full-flow filtration. Experience with other large engines such as this Ingersoll-Rand indicate that the short term benefits can included longer full-flow filter service interval, extended component life (turbochargers and rings) and in some cases, extended lube oil life. These particle count reductions and dirt trapping results show why these benefits occur.

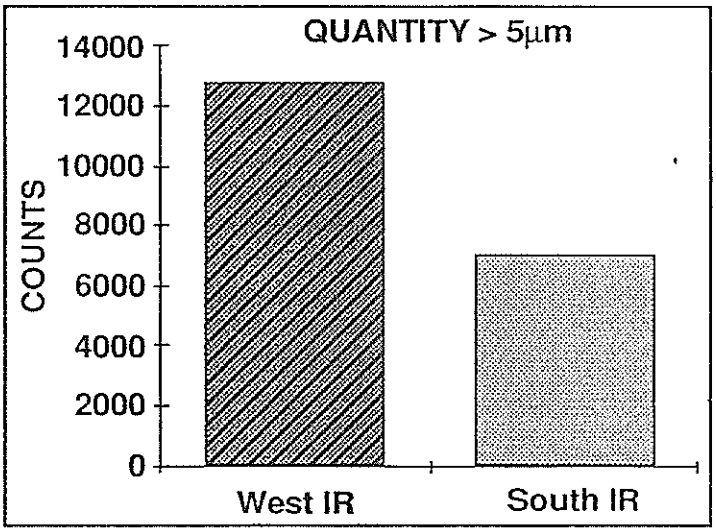


Figure 8 - Used Lube Oil Particle Counts from Integral Compressor Engine Using Screen Occlusion Method, Counts > 5μm

SCREEN OCCLUSION METHOD OF PARTICLE COUNTING

Two comparable integral compressor engines were identified by a customer to provide a baseline and test case for assessing the performance of an engine lube filtration system based only on cleanable components (see Figure 1); a cleanable filter screen element and cleanable centrifuge allows the customer to avoid the extra expense of handling and disposing of the spent filter element as a hazardous waste. The screen can be cleaned with conventional jet-spray systems, and a TCLP analysis of the solids collected in the centrifuge indicate they are safe for conventional disposal (19).

The used lube oil particle count data graphed in Figures 8, 9 and 10 attests to the ability of the centrifuge/screen filtration system to provide significantly cleaner lube oil in an operating low speed engine. Table 4 describes the characteristics of the two engines tested during this field trial. Used lube oil samples from these engines were analyzed by means of the Coulter LCM II Contaminant Measuring System, the device that employs screen occlusion as described in Table 2.

As these graphs indicate, the engine equipped with the centrifuge/screen filtration system displayed significantly cleaner lube oil at all particle size ranges. Even more importantly, the South IR unit oil sample showed this improved cleanliness at over twice the accumulated hours of the standard filter-equipped West IR unit. Photo 1 shows an element like the one used in this centrifuge/screen filtration system field trial.

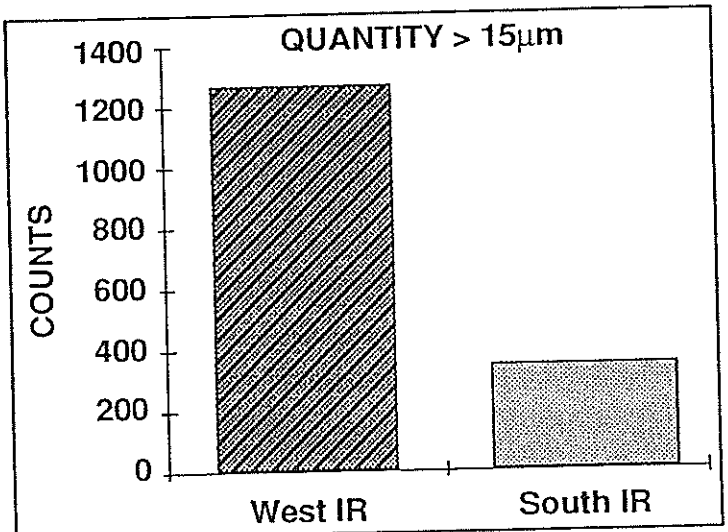


Figure 9 - Used Lube Oil Particle Counts from Integral Compressor Engine Using Screen Occlusion Method, Counts > 15µm

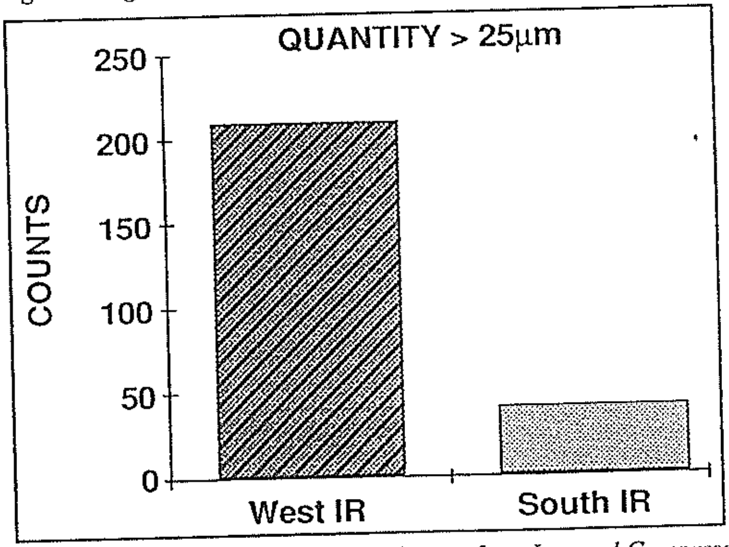


Figure 10 - Used Lube Oil Particle Counts from Integral Compressor Engine Using Screen Occlusion Method, Counts > 25µm

CONCLUSIONS

1 - Centrifuge bowl solids can provide an objective assessment of contaminants present in the lube oil of a diesel engine, by use of physical chemistry methods, Ferrographic technique and solid particle counts of the debris.

2 - An oil cleaning centrifuge removes significant volumes of abrasive debris from diesel lube oil which would otherwise remain in the oil and increase engine component wear.

3 - An oil cleaning centrifuge can trap those contaminants that a full-flow filter is unable to control, even those that are extremely small (<1 µm in size).

4 - Used oil particle counts on engines employing varying filtration strategies show that a centrifuge-equipped system can achieve very low contaminant levels, significantly cleaner than those not so equipped.

5 - A lube-powered oil cleaning centrifuge can be successfully applied to natural gas-fueled engines to reduce and control the abrasive wear debris present in the lube oil.

6 - Applying the combination of a centrifuge and a screen full-flow filter properly matched to an engine will result in cleaner lube oil than is typically possible by use of traditional media-type full-flow filters.

Unit Name	West IR	South IR
Engine	IR B412 KVSRA-212EP	IR 48 KVSRA-163S
Traits	16.25"Ø, 15" stroke, 2600HP	16.25"Ø, 18" stroke, 1600HP
Sump Volume	300 gallons	200 gallons
Oil Hours @ Sample	972	2076
Full-Flow Filter	Stacked Disc, 5µm nominal	Stainless Screen, 50 x 246 mesh
Bypass Filter	None	Spinner II Model 600

Table 4 - Installation Parameters for Field Test of Centrifuge / Screen Full-Flow Filter Combination

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®Nucleopore is a registered trademark of Nucleopore Filtration Products

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FTI, P. O. Box 669, Stillwater, OK 74076 supplied the lube oil particle counts by a process using the sample re-suspension method.

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