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Correlating Lube Oil Filtration Efficiencies with Engine Wear

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ABSTRACT

The level of filtration in an engine can have a significant impact on wear rates due to abrasive particles. Tests were conducted to establish a relationship between the level of filtration and abrasive engine wear. Although the tests were run in a laboratory environment, wear was reduced by as much as 70% by going from a 40 micron filter to a 15 micron filter.

Testing was performed on a heavy duty diesel engine and later with an automotive gasoline engine. The results from both engines were consistent and showed that the relationship developed can be applied to nearly any internal combustion recipricating engine.

INTRODUCTION

The introduction of micro glass fibers into the lube oil market now offers the capability of acheiving high levels of filtration without the traditional sacrafice of dirt holding capacity and increased flow restriction. This performance has been used to satisfy the needs of the heavy duty off road industry to extend engine life.

A cooperative effort was formed between AC Spark Plug, Detroit Diesel Corporation (formerly Detroit Diesel Allison Div. of General Motors) and CPC Div. of General Motors to establish a relationship between the level of filtration and engine wear rates. Dynamometer tests were run with various levels of filtration. The results were used to help document the benefits of high efficiency filtration in reducing abrasive engine wear.

Although it is recognized that there are many factors that contribute to engine wear, this paper deals only with the characteristics of abrasive contaminates and their effect on engine wear. By varying the level of filtration, different levels of sump contamination were achieved. From this, a relationship was established between filtration efficiency and engine wear rates.

TEST PROCEDURE

A test program was established between AC and Detroit Diesel Corporation using a 6V-53T diesel as the test engine. Later a similar test was run to evaluate the filtration performance on a 2.5L L-4 Pontiac engine.

DIESEL ENGINE WEAR — Wear rates were established by building the engine with fully inspected wear components, and again inspecting them after the test. To insure consistency from test to test, all parts were from the same manufacturer and lot number. To achieve maximum wear, 6V-53T engine conditions were established such that engine speed and torque were maintained at a steady state conditions of 2500 rpm and 500 ft. lbs. respectively. Engine oil temperature was held at 250°F.

The wear components for the test are shown in table 1.

— Upper Main Bearings
— Lower Main Bearings
— Upper Rod Bearings
— Lower Rod Bearings
— Oil Rings
— Compression Rings
— Piston Pin Bushings
— Piston Pins
— Cylinder Liners

6V-53T Diesel Engine Wear Components
Table 1

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Engine wear was accelerated to minimize test time by adding 50 grams of AC Fine Test Dust to the crankcase in slurry form every hour with a total test duration of 8 hours. Oil filters were changed when their differential pressure reached 20 psi to prevent the bypass valve from opening. Oil samples were also taken every ½ hour to track sump contamination levels. Many other engine parameters were monitored to insure consistent engine performance over the life of the test.

LEVELS OF FILTRATION

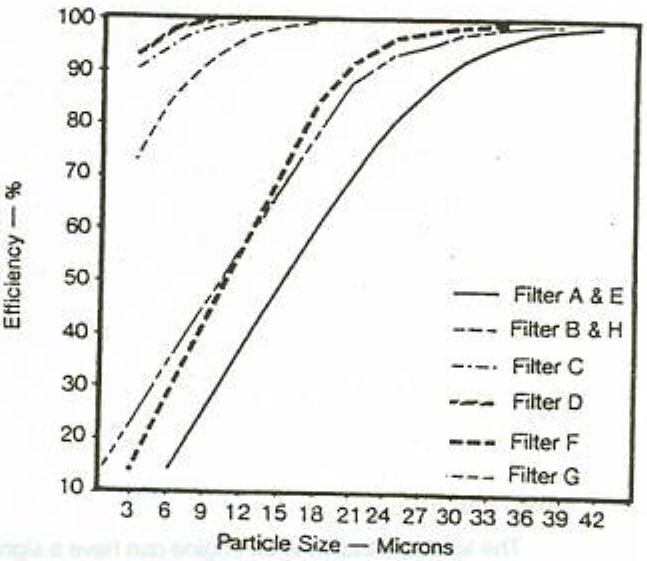
To establish a relationship between levels of filtration and engine wear rates, a variety of different filter types were selected. Since much interest has centered around the benefits of 100% glass filters, their performance was compared with the traditional more open cellulose filters. For the heavy duty test, four levels of filtration were tested. Table 2 classifies the filters' micron rating and type of media while figure 1 shows the particle retention curves for each filter type. Since pleated filters with nonwoven media have efficiencies that vary with particle size, definition of the filter's performance can be somewhat arbitrary. In this case the filters were rated at their 98% efficiency point. The single pass efficiency curves were generated by optically counting particles both upstream and downstream of the filter. Efficiencies were obtained at various particle sizes with AC Fine Test Dust used as the challenge contaminant. Figure 2 shows the particle size distribution of the contaminant based on quantity. The absolute efficiencies reported can shift somewhat depending on the specific procedure, but the shape of the curves and their relative performance will remain unchanged.

Filter	Micron Rating @ 98% efficiency	Media Composition
(A)	40	cellulose
(B)	15	glass
(C)	8.5	glass
(D)	7	glass

Diesel Filter Types
Table 2

Engine wear was established by comparing the components, weights before and after the test run. Changes in component dimensions such as bearing thickness were also tracked, but because of their sensitivity to inspection set-up conditions, they were not used in the analysis. Therefore, all analysis was done using percent change in mass only.

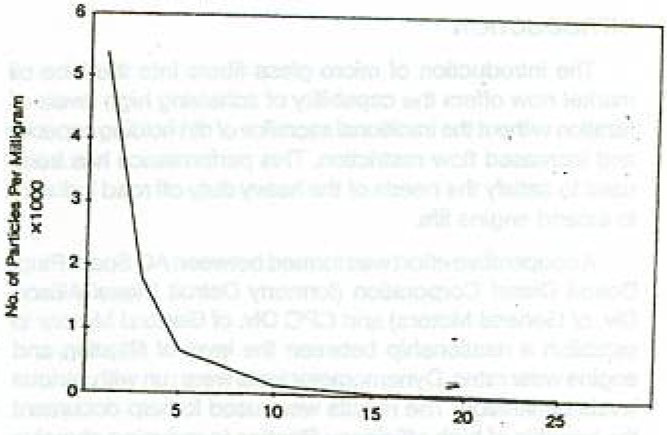
Figure 3 shows the wear of some typical components for the various levels of filtration. Those not shown graphically experienced very similar trends.



FILTER PARTICLE RETENTION CURVES
Single Pass Efficiency

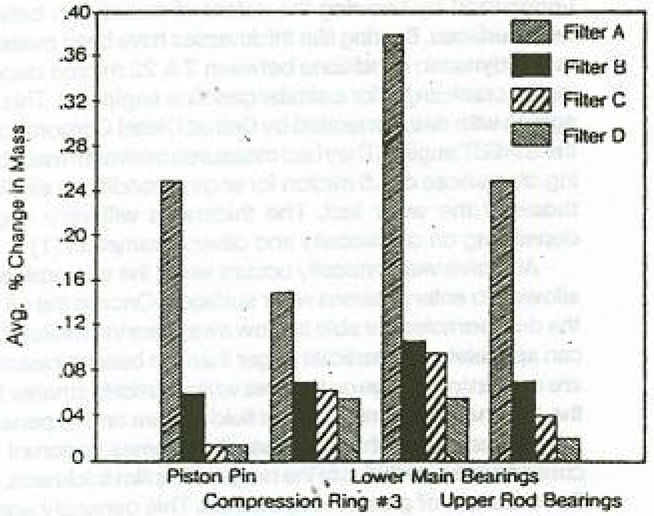
Figure 1

Sump particle contamination levels were tracked throughout the tests. Particle counts were measured using an image analyzing microscope. Sump contamination levels were then averaged over the life of the test and are shown in figure 4. Relative wear rates were also quantified through spectrochemical analysis of the oil. Figure 5 shows the average sump concentration for selected wear metals. Wear from both oil pump and cylinder contributed greatly to the iron content. Similarly, the tin, lead, and copper were generated from wear of the plating on the main bearings, rod bearings and piston pin bushings. From this, metallic concentrations can be directly correlated to engine wear. It is important to note that this analysis is used only to compare relative wear rates. Used oil analysis from engines in the field will not typically show such a clear correlation since wear metals generated between oil changes will be at much lower concentrations.



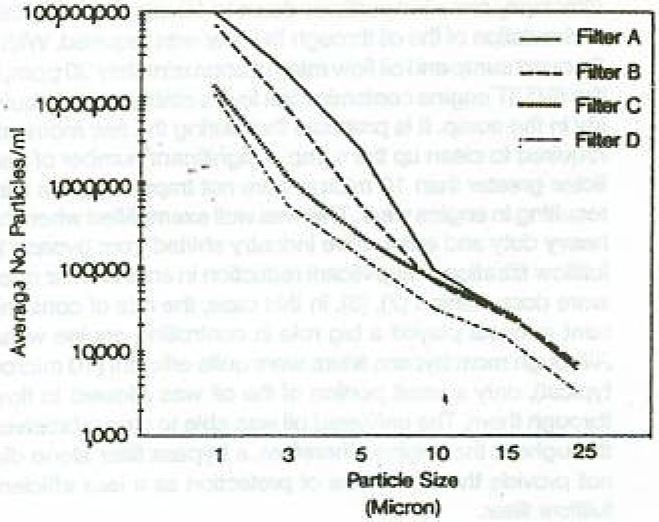
AC FINE TEST DUST
Typical Particle Size

Figure 2



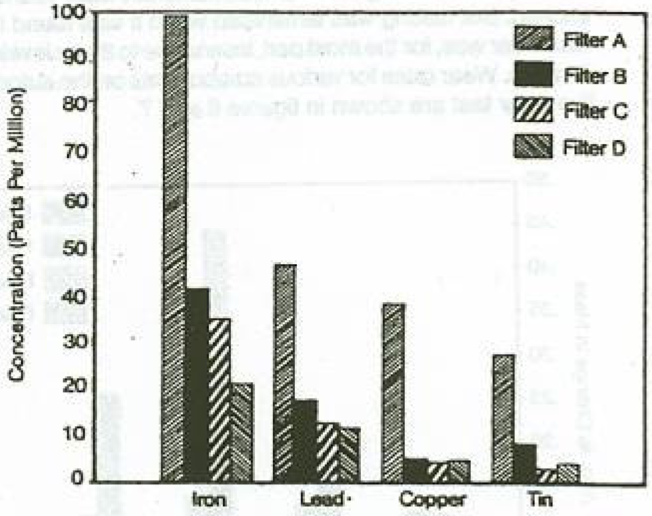
EFFECTS OF FINER FILTRATION ON COMPONENT WEAR
Diesel Engine Wear Test

Figure 3



AVERAGE SUMP CONTAMINATION LEVELS
Diesel Engine Wear Test

Figure 4



SPECTRO-CHEMICAL ANALYSIS
Diesel Engine Wear Test

Figure 5

AUTOMOTIVE ENGINE WEAR — A test similar to that run with the diesel engine was set-up using a Pontiac 2.5L L-4 gasoline engine. The test sequence was the same as that for the diesel engine except that total test time was 4 hours and the contaminant add rate was 10 grams every ½ hour. Engine speed and torque were maintained at 3200 rpm. and 106 ft. lbs. respectively. Filters were changed when their differential pressure reached 10 psi. The wear parts are shown in table 3.

— Upper Main Bearings
— Lower Main Bearings
— Upper Rod Bearings
— Lower Rod Bearings
— Oil Rings
— Compression Rings
— Cam Lobe Profile
— Cylinders

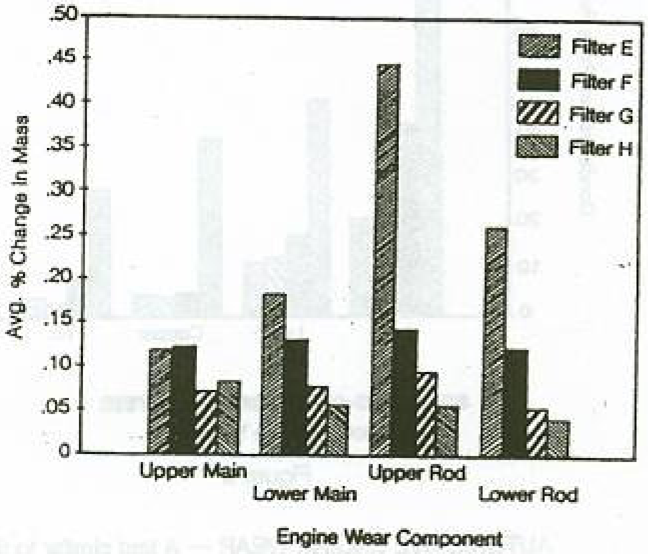
Automotive Wear Components
Table 3

Similar levels of filtration were used in the automotive test though they varied somewhat from the diesel test. Table 4 and Figure 1 show the particle retention data for each filter.

Filter	Micron Rating @ 98% efficiency	Media Composition
(E)	40	Cellulose
(F)	30	Glass/Cellulose
(G)	25	Glass/Cellulose
(H)	15	Glass

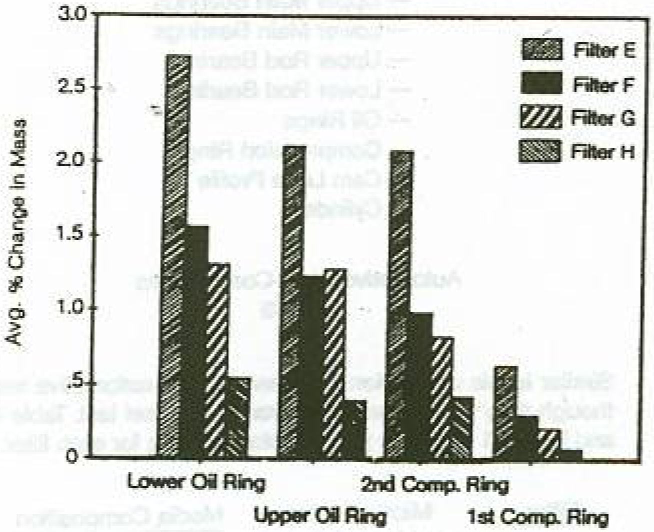
Automotive Filter Types
Table 4

Unlike the diesel engine wear test, camshaft wear was also tracked. But testing was terminated when it was found that cam wear was, for the most part, insensitive to these levels of filtration. Wear rates for various components on the automotive wear test are shown in figures 6 and 7.



AUTOMOTIVE ENGINE WEAR RATES
2.5L Engine Wear Test

Figure 6



AUTOMOTIVE ENGINE WEAR RATES
2.5L Engine Wear Test

Figure 7

ANALYSIS

An engine's sensitivity to abrasive particles can be understood by knowing the extent of clearances between wear surfaces. Bearing film thicknesses have been measured under dynamic conditions between 2 & 22 micron depending on crank angle for a similar gasoline engine (1). This also agrees with data generated by Detroit Diesel Corporation on the 6V-53T engine. They had measured minimum main bearing clearances of 1.5 micron for engine conditions similar to those of the wear test. The thickness will vary slightly depending on oil viscosity and other parameters (1).

Abrasive wear typically occurs when the contaminant is allowed to enter between wear surfaces. Once in the oil film, the dust particles are able to plow away bearing material. We can speculate that particles larger than the bearing clearance are unable to impinge on the area while particles smaller than the minimum will remain in the fluid stream and experience minimal contact with the surface. It becomes apparent that controlling the particles in the range of the film thickness, 2 to 22 micron, is of greatest importance. This generally agrees with the same range of sensitivity reported by Schilling (2). One can reason that at maximum bearing clearance conditions , particles in the range of 20 micron can enter. If they are present when the clearance is reduced to the minimum, the abrasive can plow away material from the bearing surface.

Looking at sump contamination levels for the diesel wear test provides some help in understanding the filters' abilities in removing abrasive particles. Contaminant levels varied significantly at any one time during the test. But, when averaged over the test life, significant changes in particle control between filters become apparent as shown in figure 4. Note that concentrations converged above 10 micron for all filters. Even though filter (A) was rated at 40 micron, it effectively removed particles down to 10 micron. To do this, recirculation of the oil through the filter was required. With a 24 quart sump and oil flow rates of approximately 30 gpm, in the 6V53T engine contamination levels stabilized very quickly in the sump. It is probable that during the few moments required to clean up the sump, a significant number of particles greater than 10 micron were not trapped by the filter resulting in engine wear. This was well exemplified when the heavy duty and automotive industry shifted from bypass to fullflow filtration. A significant reduction in engine wear rates were documented (2), (3). In this case, the rate of contaminant removal played a big role in controlling engine wear. Although most bypass filters were quite efficient (10 micron typical), only a small portion of the oil was allowed to flow through them. The unfiltered oil was able to carry abrasives throughout the engine. Therefore, a bypass filter alone did not provide the same level of protection as a less efficient fullflow filter.

Reviewing the particle retention curves of the filters in figure 1 shows they had varying control of abrasives in the range of 2 to 22 micron. A filter's performance in removing particles in the effective range is directly related to both its absolute micron rating and the slope of the curve in this region.

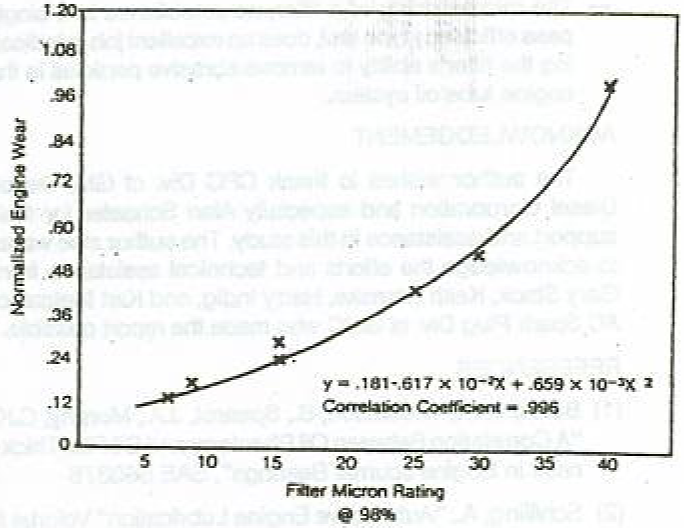
CORRELATION TO BENCH TESTS — Many bench tests have been developed over the years to rate the relative performance of oil filters. Some tests, such as SAE J806B, measure filter efficiency as a function of the contaminant mass removed over the life of the filter. This reports the filter's recirculation efficiency. Other tests like Multipass Test SAE J1858 measure the filter's instantaneous single pass efficiency by counting particles both upstream and downstream of the filter at different intervals throughout the filter's life. By comparing filter bench test performance with the engine wear data, it becomes apparent that a filter's single pass efficiency correlates very well with its ability to control abrasive engine wear. Table 5 shows the relative performance of the filters tested for both engine wear and bench tests. Wear was normalized by comparing their performance to the respective 40 micron heavy duty (A) and automotive (E) filter. Similarly, figure 8 graphically shows the correlation between single pass efficiency and engine wear.

Notice that filter (F), although it had a higher recirculation efficiency (per SAE J806B) than filter (G), proved to be no better in controlling wear. Contaminant analyses of the sumps showed that filter (F) did a better job in controlling particles smaller than 3 micron while filter (G) did a better job in controlling particles greater than 5 micron. The difference in contaminant removal above 10 micron was neglegible. In this case, filter (F) achieved higher recirculation efficiency by doing a better job in removing particles less than 3 micron and as previously discussed, particles of this size have minimal effect on engine wear. Likewise, filter (F) and (H) can be compared. Although both had nearly the same SAE J806B efficiency, filter (H) did a much better job in reducing engine wear. This results from its improved single pass efficiency which allows for better control of sump contamination levels above 3 micron.

Filter Type	Average Normalized Wear	Typical Filter Efficiency per SAE J806B	AC Micron Rating Single Pass @ 98% Eff.
(A)	1	80	40
(B)	0.29	94	15
(C)	0.18	95	8.5
(D)	0.14	96	7
(E)	1	80	40
(F)	0.5	93	30
(G)	0.46	88	25
(H)	0.3	94	15

Filter Test Performance
Table 5

Finally a four ball wear test, as defined by ASTM procedure D2266-86, was run using engine oil that had been previously aged in identical vehicles. Driving schedules and vehicle maintenance were in the same with the only difference being one vehicle used a 40 micron filter while the other used a 30 micron filter. Again the measured wear correlated directly with the automotive engine wear test. The 30 micron filtered oil generated about 50% less wear than that produced by the 40 micron filtered oil.



Normalized Wear Vs. Filter Micron Rating

Figure 8

OTHER CONSIDERATIONS

As to be expected, abrasive wear rates can be progressively reduced by increasing the level of filtration. But unfortunately abrasives are not the only wear mechanism in the lube system. Modern oil additive packages are formulated to serve many functions. The filter must also be insensitive to the oil additive package so that additives are not removed prematurely. Friesen (4) reported that the filter is capable of removing the antifoaming agent from the oil. His testing showed a sensitivity to filters 10 micron and smaller. Both pore size and media composition play a role in developing this condition. Although his testing dealt specifically with transmission fluid, some people have speculated that the same conditions could be observed in engine oil under the right circumstances. Further investigation in this area is required before any conclusions can be made.

There is also a concern that filters with smaller pore sizes will plug more quickly due to accelerated loading with sludges and resins. This is highly sensitive to both the engine and operating conditions. Field testing has shown a greater incidence of loading with high efficiency filters, but the 25 to 30 micron filters have shown more than adequate service life.

CONCLUSIONS

Summarizing the results, the following conclusions can be made:

— Abrasive engine wear can be substantially reduced with an increase in filter single pass efficiency. Compared to a 40 micron filter, engine wear was reduced by 50% with 30 micron filtration. Likewise, wear was reduced by 70% with 15 micron filtration.

— Controlling the abrasive contaminants in the range of 2 to 22 micron in the lube oil is necessary for controlling engine wear.

Continued

— The micron rating of a filter, as established in a single pass efficiency type test, does an excellent job in indicating the filter's ability to remove abrasive particles in the engine lube oil system.

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