U.S. Department of Energy
Energy Efficiency and Renewable Energy

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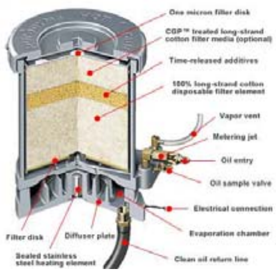
U.S. Department of Energy
FreedomCAR & Vehicle Technologies Program

Oil Bypass Filter Technology Evaluation Tenth Quarterly Report January–March 2005



TECHNICAL REPORT

Larry Zirker
James Francfort
Jordan Fielding

June 2005

Idaho National Laboratory
Operated by Battelle Energy Alliance

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Idaho National Laboratory
Transportation Technology Department
Idaho Falls, Idaho 83415

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Assistant Secretary for Energy Efficiency and Renewable Energy
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ABSTRACT

This Oil Bypass Filter Technology Evaluation quarterly report (January–March 2005) details the ongoing fleet evaluation of oil bypass filter technologies being conducted by the Idaho National Laboratory (INL) for the U.S. Department of Energy's FreedomCAR & Vehicle Technologies Program. Eleven INL four-cycle diesel-engine buses and six INL Chevrolet Tahoes with gasoline engines are equipped with oil bypass filter systems. Eight of the buses and the six Tahoes are equipped with oil bypass filters from the puraDYN Corporation; the remaining three buses are equipped with oil bypass filters from Refined Global Solutions. Both the puraDYN and Refined Global Solutions bypass filters have a heating chamber to remove liquid contaminates from the oil.

During the January to March 2005 reporting quarter, the eleven diesel engine buses traveled 97,943 miles. As of March 31, 2005, the buses had accumulated 744,059 total test miles.

During this quarter, four regularly scheduled 12,000-mile bus servicings were performed. The full-flow and bypass oil filters were changed and oil analysis samples were taken for the four buses. Bus 73446 had its oil changed due to a low total base number value. Bus 73450 had a major engine failure at the beginning of the quarter when one of its pushrods and valves were damaged. Buses 73432 and 73433 were removed from the bypass filter evaluation project and placed into the INL Diesel Engine Idling Wear-Rate Evaluation Test.

While a total of nine oil changes on the INL buses occurred during the past 29 months, 53 oil changes have been avoided by using the oil bypass filters. The 53 avoided oil changes equates to 1,855 quarts (464 gallons) of new oil not consumed and 1,855 quarts of waste oil not generated. Therefore, over 85% of the oil normally required for oil-changes was not used, and, consequently, the evaluation achieved a greater than 85% reduction in the amount of waste oil normally generated by the buses.

The six Tahoe test vehicles traveled 40,700 miles, and as of March 31, 2005, the Tahoes had accumulated 231,428 total test miles.

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Oil Bypass Filter Technology Evaluation
Tenth Quarterly Report

INTRODUCTION AND BACKGROUND

PuraDYN oil bypass filter systems (Figure 1) are being tested on eight diesel buses and six Chevrolet Tahoes (eight-cylinder gasoline engines) in the Idaho National Laboratory (INL) fleet, and Refined Global Solutions (RGS) oil bypass filter systems (Figure 2) are being tested on three diesel buses in the INL fleet. Oil bypass filters are used to extend engine oil life by cleaning solid contaminants as small as one micron out of the engine oil, as well as removing harmful liquid contaminants from the engine oil. Bypass filters from puraDYN and RGS are being used to evaluate the feasibility of reducing engine oil use and minimizing waste oil generation at INL as well as throughout the DOE complex. INL personnel that manage DOE's Advanced Vehicle Testing Activity, along with the staff from INL Fleet Operations, are conducting the oil-bypass-filter technology evaluation. Typically, the fleet of 99 buses travels established routes, carrying workers during their morning and evening trips to and from the INL test site (over 100 miles per round trip). The Tahoes are used within the 900-square-mile INL site or between the INL site and INL facilities in Idaho Falls, Idaho, a distance of 50 miles each way. The Oil Bypass Filter Technology Evaluation is being performed for the U.S. Department of Energy's (DOE) FreedomCAR and Vehicle Technologies Program. This Oil Bypass Filter Technology Evaluation quarterly report covers the evaluation period January through March 2005.

The eleven buses are equipped with the following types of four-cycle diesel engines:

- Six buses with Series 50 Detroit diesel engines (three with RGS and three with puraDYN filters)
- Four buses with Series 60 Detroit diesel engines (all puraDYN filters)
- One bus with a Model C10 Caterpillar engine (puraDYN filter).

This quarterly report covers the following:

- Status of bus mileage and performance
- Analysis and reporting of bus engine oil conditions
- Diesel engine idling wear-rate evaluation test
- Status of light-duty vehicle mileage and performance.
- Lessons learned

Table 1 lists all prior quarterly reports and the major topics presented in them.

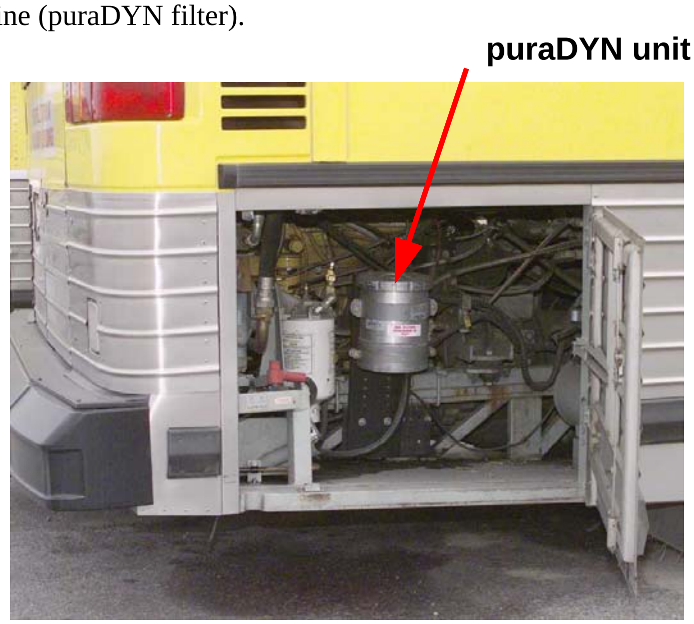


Figure 1. View of a puraDYN oil bypass filter in an INL bus. The single canister unit contains both the oil bypass filter and liquid heating chamber.

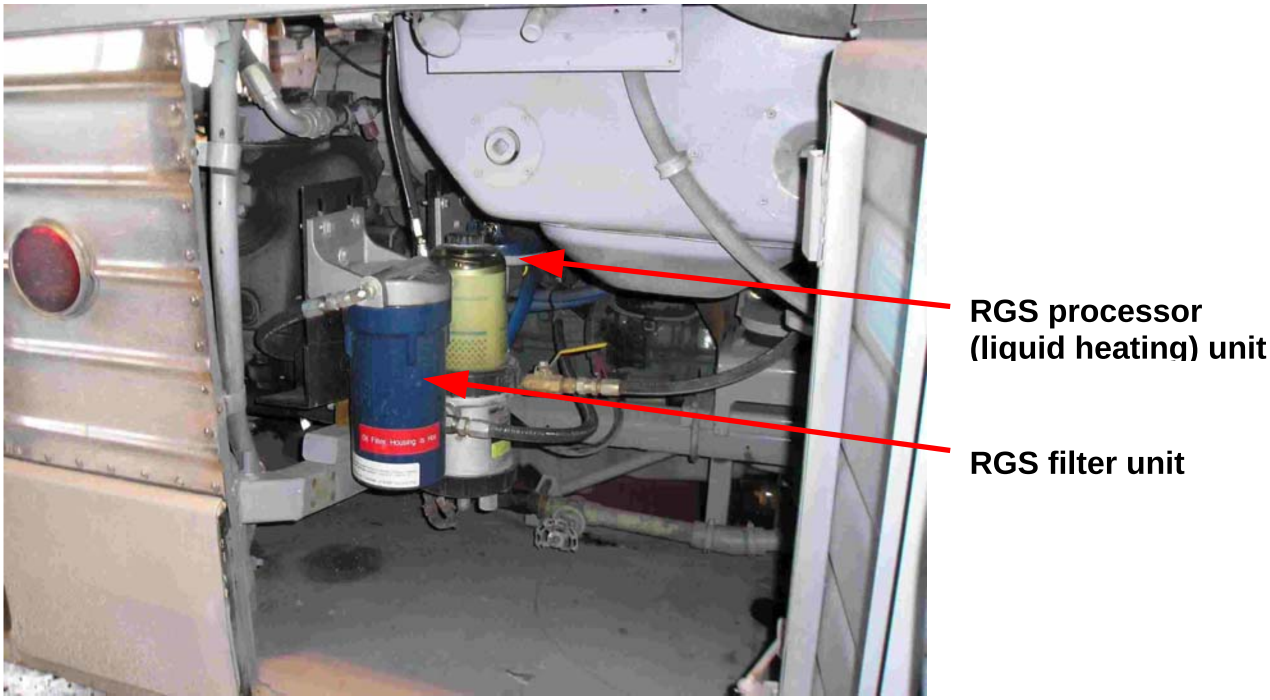


Figure 2. View of an RGS oil bypass filter and liquid heating unit in an INL bus.

Table 1. Major topics of previous quarterly reports, all of which are on line at http://avt.inel.gov/obp.

Reporting Quarter	Report Number	Major Topics
Oct 2–Dec 2 2002	INEEL/EXT-03-00129	• Background on fleet operations, vehicles, filters, and oil selection • Performance evaluation status • Economic analysis • Photographs of installed systems • Bypass Filtration System Evaluation Test Plan
Jan 3–Mar 3 2003	INEEL/EXT-03-00620	• Background on reports • Bus mileage and performance status • Revised filter replacement schedule • Oil-analysis sampling • Light-duty vehicle test status
Apr 3–Jun 3 2003	INEEL/EXT-03-00974	• Background on reports • Bus mileage and performance status • Preliminary trends in oil analysis reports • Revised economic analysis • Ancillary data • Light-duty vehicle test status
Jul 3–Sep 3 2003	INEEL/EXT-03-01314	• Background on prior quarterly reports • Bus mileage and performance status

Reporting Quarter	Report Number	Major Topics
		• Used engine-oil disposal costs • Unscheduled oil change • Light-duty vehicle test status
Oct 3–Dec 3 2003	INEEL/EXT-04-01618	• Bus mileage and performance status • Bus oil analysis testing and reporting • Light-duty vehicle filter installations • Light-duty vehicle filter installations lessons learned • Light-duty vehicle filter evaluation status
Jan 4–Mar 4 2004	INEEL/EXT-04-02004	• Bus mileage and performance status • Bus oil analysis testing and reporting • Bus engine oil particulate count analysis • Light-duty vehicle mileage and performance status • Light-duty vehicle filter evaluation lessons learned
Apr 4–Jun 2004	INEEL/EXT-04-02194	• Bus mileage and performance status • Bus oil analysis testing and reporting • Lessons learned from the evaluation of heavy-vehicle filters • Light-vehicle mileage and performance status • Lessons learned from the evaluation of light-vehicle filters
Aug–Sept 2004	INEEL/EXT-04-02486	• Bus mileage and performance status • Bus oil analysis testing and reporting • Oil use • Lessons learned on the heavy vehicle • Upcoming INEEL tests • Oil bypass filter system manufactures • Light-vehicle mileage and performance status • Lessons learned from the evaluation of light-vehicle vehicles
Oct—Dec 2004	INL/EXT-05-00040	• Status of bus mileage and performance • Analysis and reporting of bus engine oil • Diesel engine idling wear-rate evaluation test • Refined Global Solutions Filter installation • Status of light-duty vehicle mileage and performance

HEAVY-DUTY VEHICLE TESTING

Status of Bus Mileage and Performance

During this reporting quarter (January–March 2005), the 11 diesel-powered buses traveled 97,943 miles. Figure 3 shows the quarterly and cumulative evaluation miles. Table 2 details the mileage status of the eleven test buses. Figure 4 shows the total evaluation miles per bus by evaluation quarter. And Figure 5 shows the mileage per oil change history by bus.

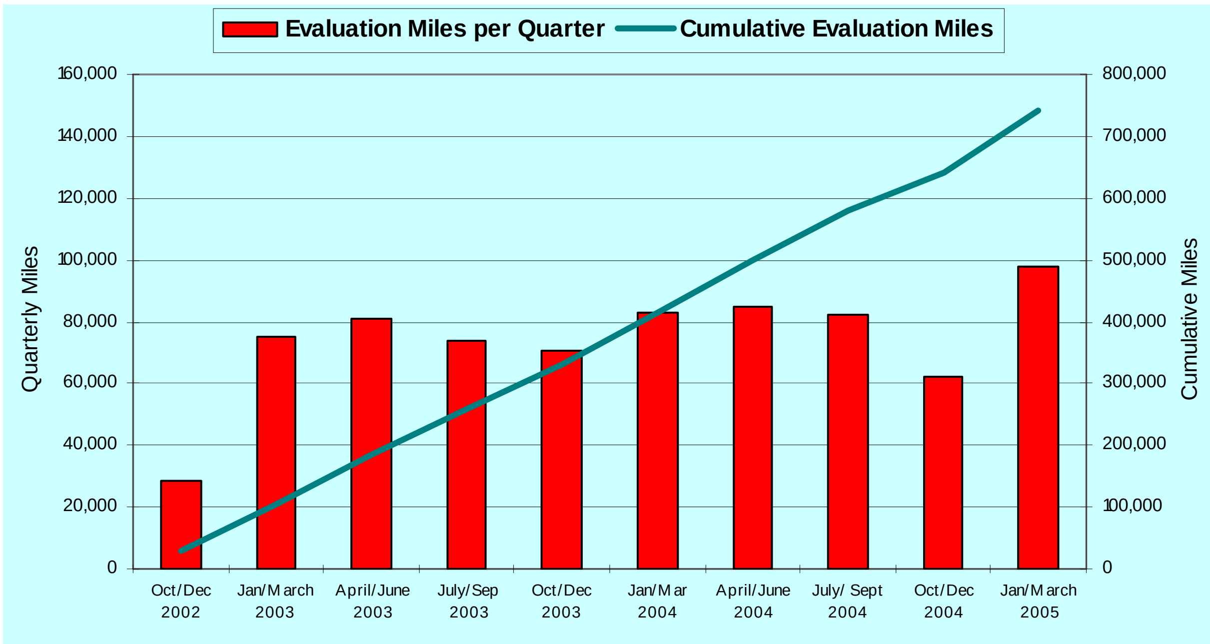


Figure 3. Quarterly and cumulative miles traveled by the test buses.

Table 2. Test buses and test miles on the bus engine oils as of March 31, 2005.

Bus Number	Filter	Start Date	Mileage at Start	Total Test Miles
73413	RGS	Dec 14, 2004	202,233	10,119
73416	RGS	Dec 14, 2004	195,156	11,044
73425	puraDYN	Dec 18, 2002	41,969	101,841
73426	RGS	Dec 7, 2004	36,140	11,352
73432	puraDYN	Feb 11, 2003	47,612	79,610
73433	puraDYN	Dec 4, 2002	198,582	100,683
73446	puraDYN	Oct 23, 2002	117,668	93,666
73447	puraDYN	Nov 14, 2002	98,069	71,713
73448	puraDYN	Nov 14, 2002	150,600	73,180
73449	puraDYN	Nov 13, 2002	110,572	71,131
73450	puraDYN	Nov 20, 2002	113,502	152,805
			Total	744,059

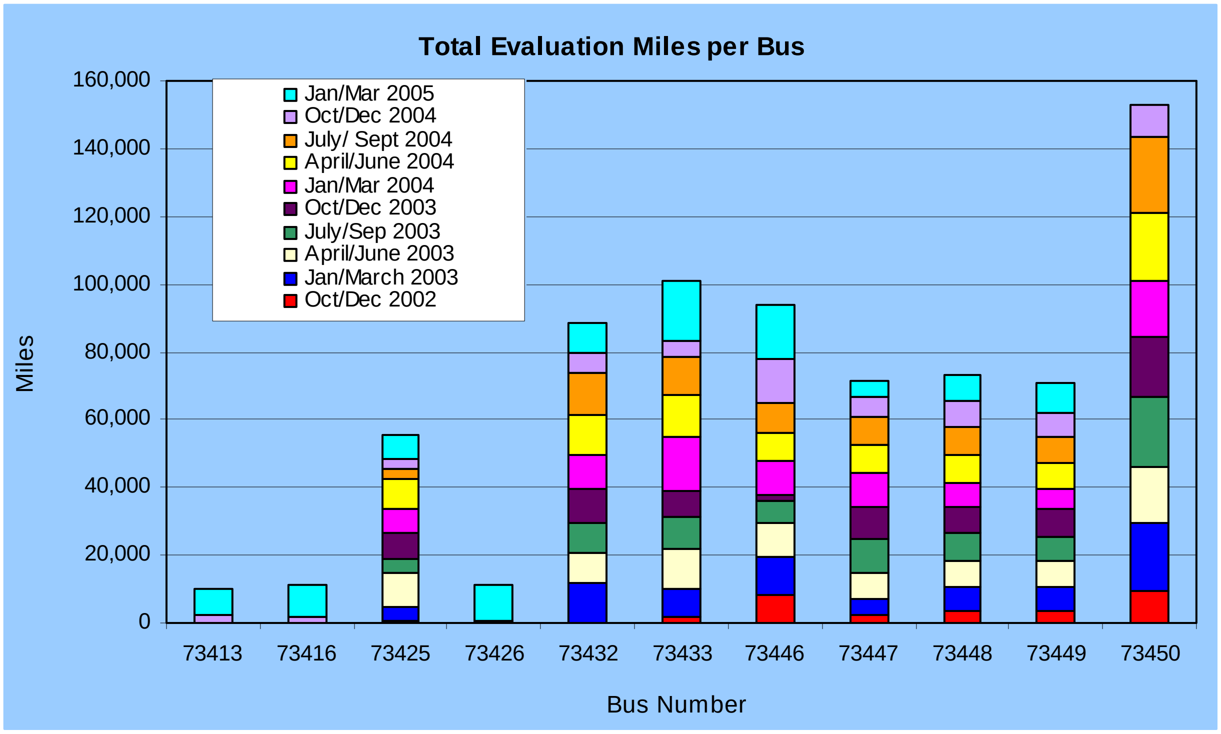


Figure 4. Total evaluation miles by bus as of March 2005.

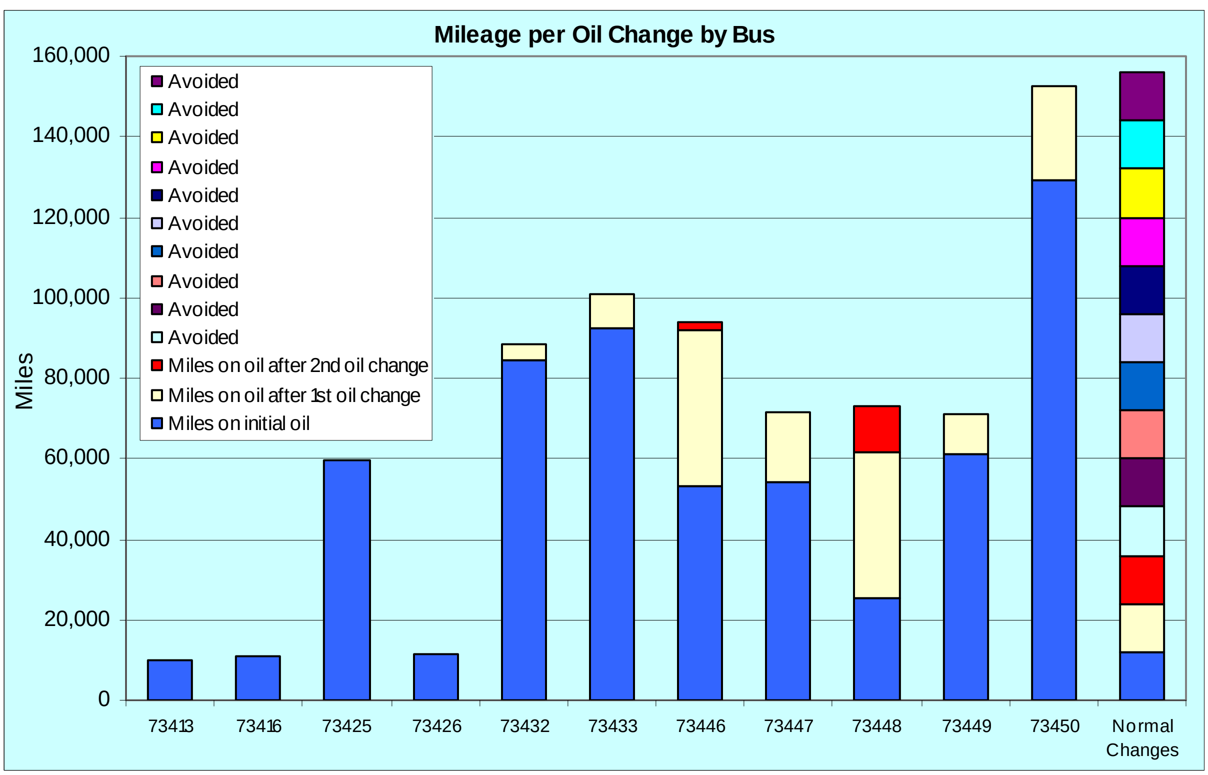


Figure 5. Test miles per oil change by individual bus. The oil on bus 73448 was first changed in error on September 16, 2003. The "Normal Changes" bar shows the number of oil changes that would have occurred if the engine oils were changed every 12,000 miles.

Analysis and Reporting of Bus Engine Oil

Four regular bus-servicing events occurred during this reporting quarter. An oil analysis report from one of the oil analysis laboratories for bus 73446 indicated that the total base number (TBN) was 2.6-mg KOH/g. This value is below the established threshold of 3.0-mg KOH/g, so a retest of the oil analysis sample was requested. Again, it came back low, 2.8 KOH/g. Therefore, the mechanics were requested to call in the bus and change its oil. Since the outset of the Oil Bypass Filter Technology Evaluation, this is the shortest distance traveled after which the oil had degraded enough to warrant changing—about 36,000 miles.

Two buses, 73432 and 73433, were transferred from the Oil Bypass Filter Technology Evaluation to the Diesel Engine Idling Wear Rate Evaluation project. The two buses had 176,936 test miles between them without an oil change. After discussions between the mechanics, fleet personnel, and test engineers, it was decided to change the oil on the buses and run them a short time with clean oil to flush out the engine oil system of any residual deleterious elements and sludge before the Diesel Engine Idling Wear Rate Evaluation project began. On February 22, 2005, both buses were called in and their engine oils were changed. On March 10, 2005, the oils and filters were again changed, and the Idling Wear Rate project began. The initial segment of the Idling Wear Rate project is to run the buses for 6,000 miles to condition the oil before initiating the 1,000-hours idling phase. It was estimated that the idling aspect of the project would be underway in May 2005.

All other bus oils were within acceptable operating conditions. Although a total of nine oil changes have occurred during the last 29 months, by using the oil bypass filters, the buses in the evaluation avoided 53 oil changes, which equates to 1,855 quarts (464 gallons) of new oil not consumed and 1,855 quarts of waste oil not generated. Therefore, over 85% of the oil normally required for oil-changes was not used, and, consequently, the evaluation achieved a greater than 85% reduction in the amount of waste oil normally generated.

Engine Failure

Bus 73450 experienced engine failure (loss of power and excessive exhaust smoke, according to the service report) during the first workday of the reporting quarter. Bus 73450 was towed to the INL maintenance shop for diagnosis, and the engine was eventually removed from the bus and the valve covers removed. Postmortem analysis revealed that the valve train was out of adjustment and parts were worn. The mechanic discovered the bolts holding one of the rocker arms had worked loose (unscrewed) about 0.25 inch. With so much play in the rocker arm, the rocker arm and the push rod were severely worn, and eventually the push rod became disconnected from the rocker arm and was bent. This allowed the valve to drop into the cylinder, and to be struck and broken into pieces by the piston. With the valve missing, the engine lost power and began to smoke. It was determined that the engine failure was unrelated to the use of the oil bypass filter. Inasmuch as this was the only Caterpillar engine in the 99 INL bus fleet, it was decided not to repair the engine but to replace it with a Detroit Diesel series 60 engine.

Diesel Engine Idling Wear-Rate Evaluation Test

INL is undertaking a diesel engine idling evaluation in support of DOE's effort to minimize the time diesel engine trucks are left idling. Over 850 million gallons of diesel fuel are consumed during periods of engine idling for heating, cooling, and auxiliary power generation. The evaluation will characterize diesel engine wear and lubricant degradation during extended periods of engine idling: two INL buses equipped with Detroit Diesel Series 50 engines will be idled for 1,000 hours each.

It is believed there may be operational and economic benefits from the reduced engine wear, and, possibly, engine-life and oil-change intervals will be extended, but there is no definitive consensus on the economic value of these benefits. Therefore, the two buses from INL's oil bypass filter evaluation project were selected as test buses. These buses were selected because there is over two years of oil analysis background data on which to build the idling test database. In addition to the current oil analysis, engine-wear metals will be characterized by analyzing the engine oils and by destructively analyzing the bypass and full-flow oil filters to measure the engine-wear metal particles captured.

To develop baseline data before starting the idling test, the bypass oil filter and one full flow oil filter from buses 73433 and 73432 were sent to National Tribology Services (NTS), Inc., of Minden, Nevada for analysis. A secondary benefit of this initial destructive analysis is to establish and refine the filter testing protocol before the filters from the test period are examined. There is only one opportunity to capture the data from the filters, as the examination is very intrusive and not repeatable with the same filter.

Analytical Ferrography

The tribologists (oil scientists) and laboratory technicians at NTS have conducted analytical ferrography on the oil from both test buses. There are five sources of analysis oil from each bus:

- One used oil sample is taken directly from the engine via a pressurized line feeding the bypass oil filter system.
- When the filter media is removed from the two filter canisters (one of the two full flow filters and the bypass filter), there is about 100 ml of oil residue in the bottom of each of the canisters. When the initial filters were sent into NTS, their technicians discovered this residue, and they analyzed it of their own initiative, because they knew of the investigative nature of this test and that it would create another data point. NTS has continued this practice since then, and it is theorized that when more of these residue samples are taken, valuable comparisons and trends will be established.
- A one-pound section of each filter (one of the two full flow filters and the bypass filter) is placed into 24-ounces of neutral base oil (oil with no additives) and given an eight-hour ultrasonic cleaning. The sonication of the filter media separates the contamination from the filter media and captures the contamination (engine wear metal particles) in the neutral base oil. Two oil analysis samples are taken from this "brew" of contaminated oil and tested.

The five oil analysis samples are given a complete suite of tests to characterize the engine wear metals, additives, and oil quality. One of the tests is called analytical ferrography, which is a process wherein a small volume of oil is poured across a glass slide that is setting on a strong permanent magnet. The strongly magnetic iron particles are initially captured in the entry region of the slide where the oil is first poured onto the slide. They are captured on the glass by the magnetic lines of flux and align with them as they traverse the slide. This is why ferrograms have striations or bands of particles and not completely coated with iron particles. Both the small and large iron particles congregate together and stack up as rows on the glass. The nonmagnetic or paramagnetic items—silicon, aluminum, lead, etc.—will randomly stick along the rows of iron as they flow over the glass slide. After the particles are captured, the slide is then carefully washed with a solvent to remove the oil but not wash off the iron particles. The slide is photographed with a bichromatic microscope configured with both reflected and transmitted light sources illuminating from both above and below the stage. Figures 6 and 7 show sketches of the ferrography process.

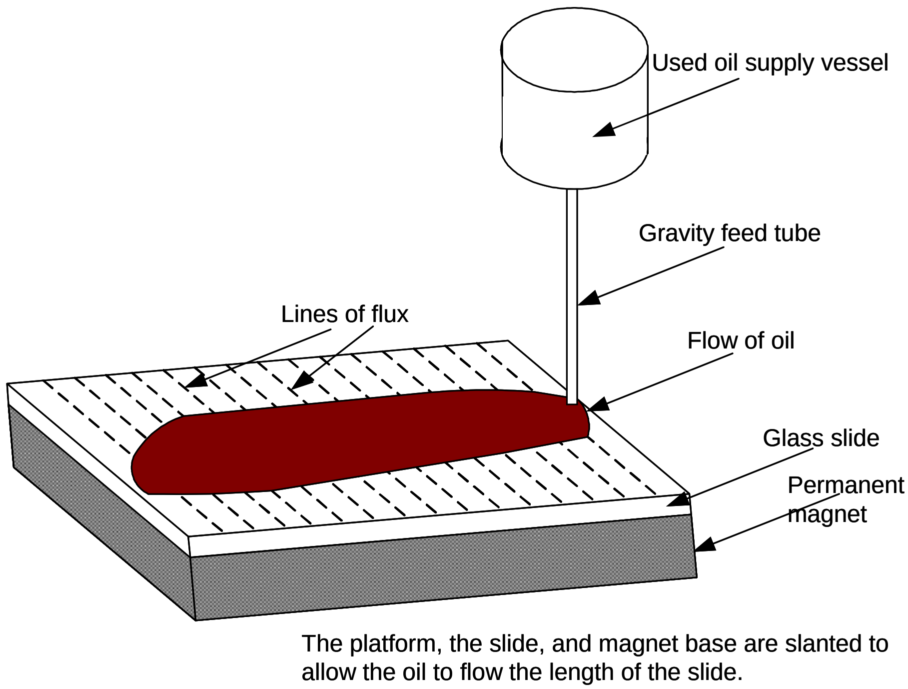


Figure 6. The making of a ferrogram.

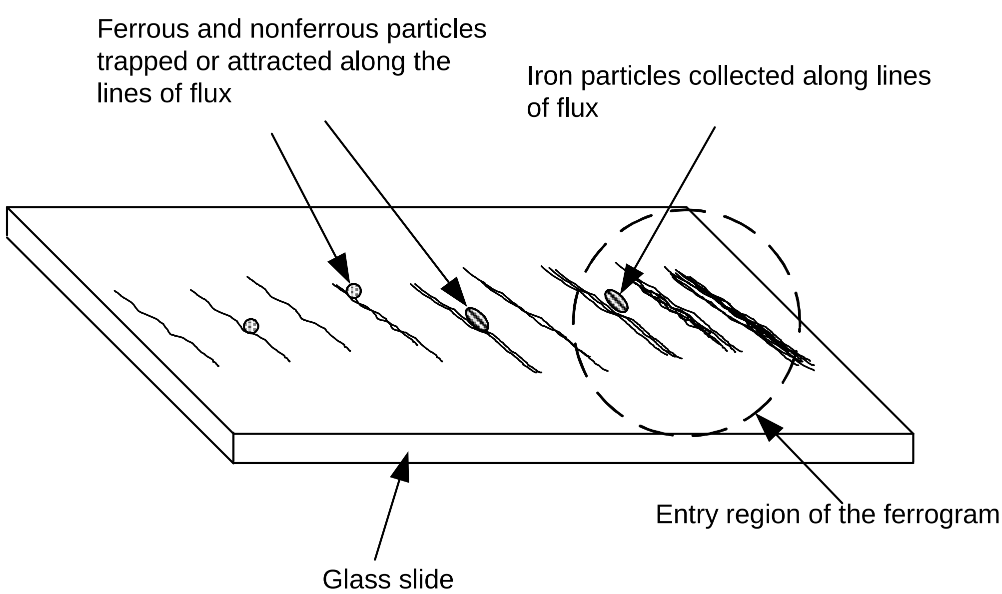


Figure 7. Detail of particles on the cleaned glass slide.

Since iron is the predominant engine wear metal present in these engines, ferrogram photographs are an excellent tool to compare engine wear between the service intervals of the idling test. It is estimated that ten sets of ferrograms will be available over the idling test to graphically compare the engine wear. Ferrograms selected from the pre-idle test phase are presented in Appendix A. These ferrograms are the initial baseline set of data and will provide comparisons for subsequent ferrograms.

Filter Effectiveness

One aspect of the idle test is to use the bypass filter to capture most of the small particles and then through destructive analysis retrieve the particles for laboratory analysis and testing. As stated, there are five sets of oil analysis reports for each of the three destructive filter analyses. The fine particles are measured with atomic emission spectroscopy, which measures particles of generally less than ten microns. The larger particles are captured and characterized by rotrode filter spectroscopy (RFS) analysis. RFS captures particles of 10 to 50 microns. Figure 8 shows the five oil analysis samples from each of the three destructive filter analyses. Since a one-pound section of the 9.6-pound bypass filter and a one-pound section of the 1.4 pound full-flow filter were sonicated to extract all of the particles captured by the filters, the final amount of particles captured needs to be adjusted to more accurately reflect what was captured by the filters.

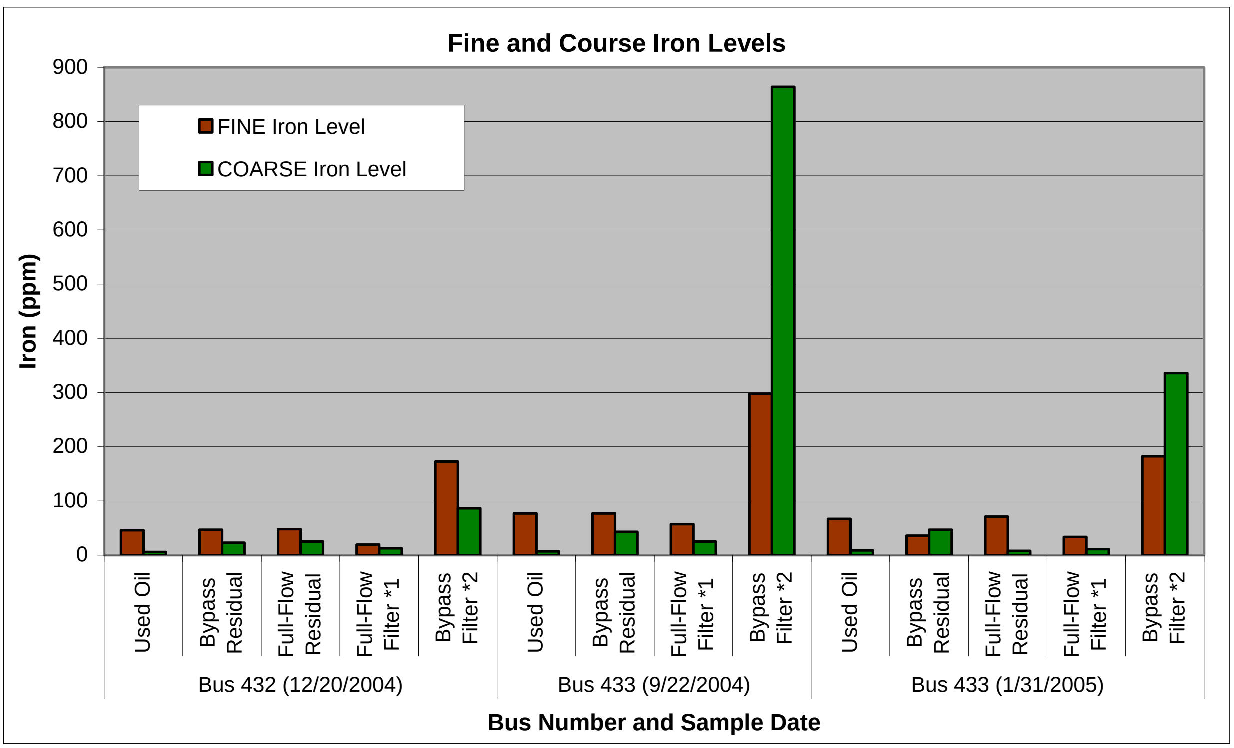


Figure 8. Fine and course iron levels from the buses in the idling test. *1: PPM values are adjusted to reflect all of the particles captured by the filter. *2: PPM values are adjusted to reflect all of the particles captured by the filter.

LIGHT-DUTY VEHICLE TESTING

Status of Light-duty Vehicle Mileage and Performance

The light-duty Tahoes traveled 39,517 miles during this reporting quarter, and there were 13 servicings events. However, six of the servicings were when the all of the Tahoes were called in for an engine oil change. This restart of the evaluation was necessary due to the inconsistency in the data. Two events brought the inconsistency to light. There was some difficultly maintaining desired TBN oil levels with the light-duty vehicles. So last fall, when a puraDYN representative visited INL to review the light-duty vehicle data, he suggested that a larger orifice might increase oil filtration rates. PuraDYN supplied a larger orifice in the metering system to increase the oil flow to the bypass filter system in order to filter more oil and to increase TBN levels. But this change (which increased oil flow) did not noticeably help with the low TBN values. In addition, though the INL test engineers believed the oil was being changed at each 3,000-mile service (in an attempt to level out the TBN values), review of the oil analysis reports showed that sometimes the oil values improved and sometimes they declined. Then, early this quarter, when the regular service mechanic was changed and the directions on the electronic service work orders for the Tahoes were explained, it was discovered that the regular mechanic had misinterpreted the directions and had not changed the oil as intended by the directions. The confusing data were explained: the various alternate mechanics would change the oil as directed in the work order, whereas the regular mechanic did not. This quarter, a new mechanic was permanently assigned to the light-duty vehicles, and the test was restarted.

During this reporting quarter, the oil bypass filter system in Tahoe 71333 was disconnected. This Tahoe is a security vehicle, and it could not be out of service for an extended period. When it was in for servicing, the mechanics disconnected the oil bypass filter system because the service mechanic who had the smaller cold weather orifice (0.0156-inch) was not at work that day. The vehicle has had multiple problems with leaking oil out of the overflow vent, and disconnecting the system was the only remedy at the time.

Lessons Learned

The following lessons were learned during the quarter:

- Even the intuitively obvious aspects of the bypass filter systems must be included in the installation handbooks or manuals. The RGS filter systems were installed in December 2004, and the service mechanic installed the system according to the requirements of the factory-furnished installation handbook. In December, both the INL test engineer and the RGS representative inspected one of the buses after their systems were installed. Several weeks later, the INL Fleet Operations point of contact for the test called the RGS test engineer and reveled that there was not a tee fitting nor valve in the system to allow taking of oil analysis samples. The RGS engineers were contacted, and they sent parts for the three buses. Subsequently, the RGS engineer reworked their installation handbook to include installing a tee fitting with a sampling valve.
- Having a bypass filter system does not negate conducting regular engine and filter maintenance. Oil bypass filter system representatives reported that a common problem occurs when users tend to forget or neglect aspects of engine maintenance after they have oil bypass filter systems installed. It is true that filter system will reduce end users use of new oil and disposal of used oil, but the system does not manufacture oil for the engine—it just super cleans it. The engine oil must be topped off as needed, especially when filters are replaced.
- It is essential to track the wear rate ratios for extended oil drains to catch any increased trends in wear. An increased wear ratio is an indicator something is occurring in or to the engine. It is

especially important to continue the wear rate ratio calculations after the oil has been changed. With few miles, the ratio will be higher for engines with an imminent engine failure problem.

SUMMARY

Oil bypass filter systems are being tested on eleven INL buses. To date, the eleven buses have accumulated 744,059 miles since testing inception (October, 2002). Nine oil changes have been performed on the INL buses since the start of testing, and the buses have avoided 53 oil changes. This equates to 1,855 quarts (464 gallons) of new oil not consumed and 1,855 quarts of waste oil not generated, which equates to an 85% savings on oil purchases for oil changes and waste oil generation.

The six Tahoe test vehicles traveled 40,700 miles, and as of March 31, 2005 the Tahoes had accumulated 231,428 total test miles.

TBN values (2.6 mg KOH/g) for bus 73446 fell below the predetermined quality value limit (<3.0 mg KOH/g), and its oil was changed.

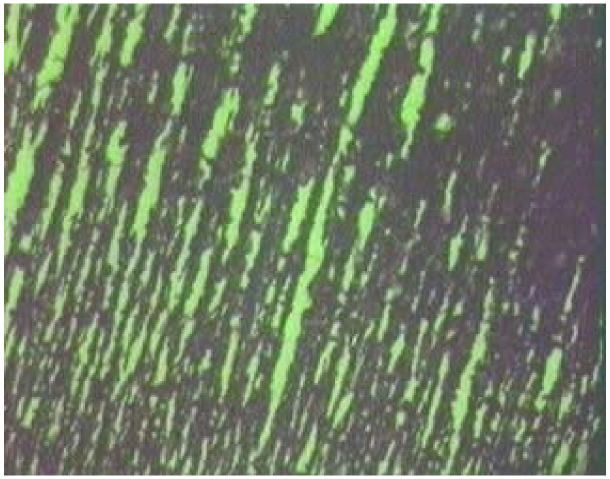
Two buses, 73432 and 73433, were removed from the Oil Bypass Filter Technology Evaluation and placed into the Diesel Engine Idling Wear Rate Evaluation project. There were 176,936 test miles between them without an oil change.

Bus 73450, with the Caterpillar engine, had engine failure. One set of rocker arm bolts became loose, and the pushrod became disconnected, allowing a valve to drop into the cylinder.

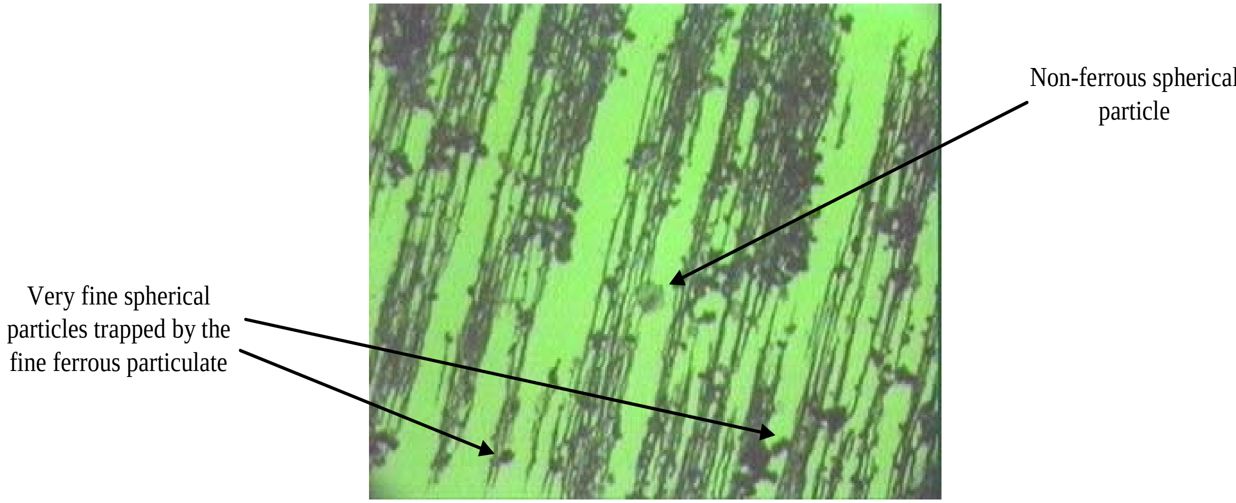
A second set of filters from bus 73433, one bypass and one full flow filter, were sent for destructive analysis for the idling project. This is the last set tested before the idling phase. The results of this analysis will become the baseline data for subsequent comparisons, and this analysis helped refine the analysis procedures, which ensures complete characterization of data in future filter analyses. The actual bus idling is scheduled to begin in May, 2005.

APPENDIX A – SELECTED FERROGRAMS

Idle Test Ferrograms								
Bus Number	**Oil Source**	**Sample Date**	**NTS Sample Number**	**Test Stage**	**Total Miles and Hours on the Oil**	**Magnification**	**Photograph Number**	**Region of Slide**
73432	By pass residual	12/20/05	87759	baseline	79053 miles	100x	87759-A	Entry
Comments	Three ml of oil from the neutral base oil after ultrasonic cleaning of the full flow filter media is the oil tested with this ferrogram. Ferrogram shows a moderate amount of fine (<10 µm) ferrous particulate, typical of normal rubbing wear.							
Special Features	Very fine ferrous debris. Density 5							



Idle Test Ferrograms								
Bus Number	**Oil Source**	**Sample Date**	**NTS Sample Number**	**Test Stage**	**Total Miles and Hours on the Oil**	**Magnification**	**Photograph Number**	**Region of Slide**
73432	By pass residual	12/20/05	87759	baseline	79053 miles	100x	87759-B	Representative of slide
Comments	Three ml of oil from the neutral base oil after ultrasonic cleaning of the full flow filter media is the oil tested with this ferrogram. Ferrogram shows a moderate amount of fine (<10 µm) ferrous particulate, typical of normal rubbing wear.							
Special Features	Arrows show spherical particles are trapped along with the fine ferrous particulate. Very fine ferrous debris. Density 5							



Idle Test Ferrograms								
Bus Number	**Oil Source**	**Sample Date**	**NTS Sample Number**	**Test Stage**	**Total Miles and Hours on the Oil**	**Magnification**	**Photograph Number**	**Region of Slide**
73433	Used oil	12/20/04	87940	Baseline	79053	500x	97940 -B	Entry Point 7
Comments	Ferrogram shows a light amount of fine (<10 µm) ferrous particulate, typical of normal rubbing wear. A light amount of ferrous cutting wear, ferrous laminar and sliding wear particulate (~50 microns), soot particles, dark metallo oxide, fibers and sand/dirt was noted.							
Special Features	Please see attached images of ferrous cutting wear and of sliding wear