



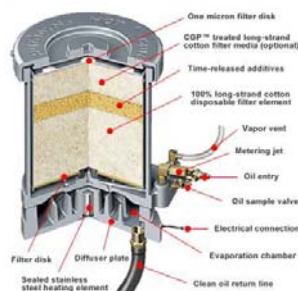
**U.S. Department of Energy
FreedomCAR & Vehicle Technologies**

**Oil Bypass Filter Technology
Performance Evaluation**

First Quarterly Report

*Larry Zirker
James Francfort*

January 2003



*Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC*



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**Idaho National Engineering and Environmental Laboratory
Transportation Technology and Infrastructure Department
Idaho Falls, Idaho 83415**

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ABSTRACT

This report details the initial activities to evaluate the performance of the oil bypass filter technology being tested by the Idaho National Engineering and Environmental Laboratory (INEEL) for the U.S. Department of Energy's FreedomCAR & Vehicle Technologies Program. Eight full-size, four-cycle diesel-engine buses used to transport INEEL employees on various routes have been equipped with oil bypass systems from the puraDYN Corporation. Each bus averages about 60,000 miles a year. The evaluation includes an oil analysis regime to monitor the presence of necessary additives in the oil and to detect undesirable contaminants. Very preliminary economic analysis suggests that the oil bypass system can reduce life-cycle costs. As the evaluation continues and oil avoidance costs are quantified, it is estimated that the bypass system economics may prove increasingly favorable, given the anticipated savings in operational costs and in reduced use of oil and waste oil avoidance.

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Oil Bypass Filter Technology Performance Evaluation January 2003 Quarterly Report

INTRODUCTION AND BACKGROUND

This is the first quarterly report of the oil bypass filter technology performance evaluation.¹ Eight puraDYN oil bypass filter systems (Figure 1) are being tested on Idaho National Engineering and Environmental Engineering Laboratory buses (Figure 2). The eight buses are all equipped with four-cycle diesel engines:

- Three Series-50 Detroit Diesel engines
- Four Series-60 Detroit Diesel engines
- One Caterpillar engine.

Most of the effort to date has been spent preparing the test plan, receiving INEEL organizational approval (including management and health and safety groups), ordering parts, installing the oil bypass systems, performing the initial engine oil changes, and accumulating the initial testing miles. Test data are accumulated as the buses log miles once the bypass filters have been installed and oil changes are avoided. By the end of the quarter (December 2002), the combined miles logged by the buses was approximately 30,000 miles. As more miles are traveled, subsequent data will be accumulated, enabling an expanded evaluation of the oil bypass filter system.

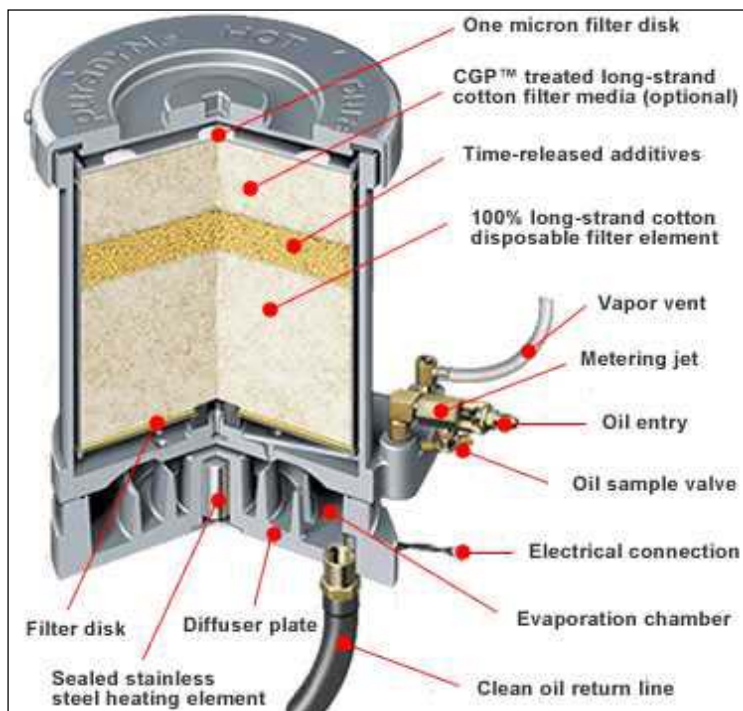


Figure 1. Drawing of a puraDYN oil-bypass filter.

This test has three main tasks:

1. Evaluate the performance of an advanced commercial oil bypass filter technology
2. Expand the evaluation and analysis to other vehicles within the DOE system
3. Furnish an economic analysis and report.

The benefits to DOE and the nation of safely extending oil drain intervals include:

¹ The DOE FreedomCAR and Vehicle Technology Program Office funds these activities.

- Decreasing dependence on foreign oil
- Reducing the generation of waste oil
- Reducing equipment downtime
- Reducing investments in handling/changing motor oil
- Reducing oil-related environmental issues—spills, drinking water contamination, and waste oil handling.



Figure 2. INEEL passenger bus.

INEEL Fleet Operations

A team of about 30 mechanics and service personnel perform maintenance and repairs on the INEEL fleet of about 1,500 vehicles. Although the first function of the INEEL's 81,672-ft² Fleet Operations Facility is operations, it presents an excellent environment for transportation technology development projects. The fleet of 99 buses is unique to the DOE and offers an excellent test bed for development projects of this type. Seven of the 99 buses operate on liquid natural gas. The other 92 operate on diesel fuel. The INEEL also has a light-duty vehicle fleet of about 600 vehicles. The light-duty vehicles are being evaluated in terms of miles driven annually, total miles accumulated on each vehicle, and the possibility of installing oil bypass systems on various models in order to expand the test fleet. Installation depends on the space available in the engine compartment and on compatibility of the systems.

Test Bus Selection

INEEL buses transport over 2,500 workers from local communities to remote work locations at the INEEL site, located about 60 miles from the cities of Idaho Falls and Pocatello. The buses transport workers from four directions, averaging a daily round trip of about 150 miles per bus; the buses also have additional shuttle activities. The eight buses selected for this test all have relatively new diesel engines—between 40,000 and 190,000 miles. Since they are newer, they are selected by the more senior drivers, who have extra driving duties or shuttle routes. The eight buses all operate on fairly similar routes, accumulating both city and highway miles, and average about 60,000 miles a year each. In addition, the buses have had consistent and controlled maintenance. Bus mileage is recorded with each fueling, tracking mileage accumulation and need for maintenance.

Bypass Filter Technology

The testing activities included installation, use, and evaluation of an oil bypass system from puraDYN Filter Technologies Incorporated, located in Boynton Beach, Florida. puraDYN has been in the oil bypass filter business for 17 years and has thousands of filters installed throughout the country. They have multiple filter system sizes and models. The filter system selected for the eight INEEL buses is the PFT-40, designed for 40-quart engine oil capacity. Following are a few details about the puraDYN system:

- The system does not replace the conventional full-flow oil filter system but works in conjunction with it

- The filter system hardware is connected to the engine oil supply system downstream of the standard engine oil full flow filter
- The system does not appear to negatively affect the engine's oil flow or pressure
- The oil treated by the bypass system is gravity-fed back into the oil pan
- The replaceable tightly compressed long-strand cotton fiber bypass oil filter is reputed to resist channeling and to remove contaminants to less than one micron
- The manufacturer states that the flow rate through the system is six to eight gallons per hour
- There are no moving parts.

A puraDYN system has two main components: the filter housing and the replaceable filter cartridge. Both components have attributes that appear to be unique to the puraDYN system:

- The bottom of the filter housing has a heated chamber to volatilize and vent fuel and coolant liquids that contaminate oil
- The replaceable filter has a patented time-release oil-additive package embedded in the cotton fibers that neutralizes acid compounds that build up in oil during combustion
- As the oil seeps through the filter, it picks up the acid reducing additive elements, replacing the initial oil additives consumed during combustion
- The additives enhance the total base number (TBN) value of the oil. The TBN is an indicator of oil quality, and when it falls below 3.0 an oil change is recommended.

Additional advertised benefits of the puraDYN's oil bypass filter technology include:

- Extended oil drain intervals
- Reduced frictional engine wear
- Reduced oil purchases of up to 90%
- Reduced waste oil costs of up to 90%
- Reduced vehicle downtime and improved productivity
- Additive levels that remain within acceptable limits
- Better-maintained oil viscosity
- Improved oil circulation
- Decreased sludge and varnish deposits
- Fast payback.

Oil Selection and Analysis

Oil Selected

The engine oil normally used for the INEEL light- and heavy-duty fleet has 20% recycled products (America's Choice). For the test, however, the INEEL wanted to use a premium grade of oil in common use and to reduce any test variables relating to using recycled oil. The oil selected for the test is Shell Rotello-T, 15W-40. Fleet Operations personnel selected this oil, but its widespread use was later confirmed by surveying six tractor-trailer trucking companies. Four use the Shell Rotello-T oil.

Oil Analysis

When extending oil drain intervals, it is imperative to know the fitness of the engine lubricating oil and to establish the wear pattern trends of the engine. To evaluate the effectiveness of the bypass technology, the oil is periodically analyzed. Oil analysis reports verify and validate the fitness-for-service of the oil. The results of each analysis are compared to historical standards and to industry standards. To ensure the quality of data, two oil-analysis laboratories were contracted for this test. At each filter service period during the test, a 200-ml container of engine oil is shipped to both laboratories, and an archive sample is retained in a fireproof cabinet within the Fleet Operations Facility for future reference. The two oil-analysis laboratories are CTC Analytical Services of Phoenix, Arizona and ANA Laboratories, Inc. of Bellmawr, New Jersey.

OIL BYPASS SYSTEM PERFORMANCE EVALUATION STATUS

The four main evaluation activities are:

1. Test preparation
2. Oil bypass system installation
3. Oil bypass system operations and evaluation
4. Economic analysis of the oil bypass system.

Test Preparation

Preparing for the test included writing a test plan and completing pretest prerequisites. These were conducted in parallel. The goal of the test plan (Attachment 1 - INEEL PURADYN Oil Bypass Filtration System Evaluation Test Plan, EVH-TP-146, Rev 0, October 2002) is to measure the effectiveness of the puraDYN oil bypass system in order to safely extend oil drain intervals. The major tool for measuring the fitness of the engine oil is regular independent oil analysis tests.

Sixteen prerequisites tasks were identified during the planning stages for the test, which were addressed as part of the test readiness assessment prior to filter system installations. A target installation date of late November was selected, and all but one of the tasks were completed before the installation date. The pretest tasks fall under the following topics:

- Parts and supplies. All parts and suppliers were staged at the Fleet Operations Facility before installation. This included securing oil analysis kits from both oil-analysis laboratories.
- Safety. All safety and environmental concerns relating to the filters, oil, installation of the filter system, and the test plan were addressed and resolved before installation.
- Training. All bus driver and mechanic training relating to the test was performed before installation.
- Bus selection. Eight four-cycle diesel engines were selected from the bus fleet.
- Test plan. The stakeholders (including safety and health organizations) reviewed and approved the test plan before installation.

Only one pretest task—entering the oil filter servicing schedule into the tracking software—was not met; the INEEL Fleet Operations management changed their fleet and maintenance tracking software, and it was not mature enough at the time of installation to track the oil filter-servicing schedule.

Oil Bypass System Installation

When the INEEL mechanic began to install the first oil bypass system, he discovered an overlooked detail, which stopped the installation process. The initial set of filter systems were ordered with 12-volt heating elements in the heating chamber of the filter housing. Twelve-volt power is not available in the engine compartment, but only available at the front of the bus. Prudence directed not stringing 45 feet of wire from the front of the bus to the back to power the heating element. Therefore, new 24-volt heating elements were ordered from puraDYN.

When the new heating elements arrived, it was discovered that they were 0.1 inch too long and would not fit into the bottom of the filter housing. Instead of sending the filter housings to a machine shop, it was decided to return all of the puraDYN filter systems in exchange for systems with the correct size heating element openings and factory installed 24-volt heating element. When the replacement filter systems arrived within a week, installation continued.

The steps in the installation procedure established in the test plan were modified during the first installation. The initial plan was to drain the old oil and install the new Shell oil, and then each bus would be driven to another service bay for the filter installation, since different mechanics perform oil changes and hardware installations. The mechanics quickly changed the sequence of steps to first install the filter system without connecting the oil lines. After moving the bus to the oil change bay, the oil is drained and then the oil supply and return hoses are connected, and finally the new Shell oil is added. This averted an oil spill when removing the below-the-oil-level plug fitting in the oil pan.

When the three buses with the Series 50 engines were examined before installation, it was discovered that there was no assessable space to mount the filter housing or assembly. These three buses have an on-board restroom that fills the right-rear engine compartment. This compartment is accessed via a hinged door. Upon examination, it was decided to install a hinged access door on the left-rear side of the bus to access heretofore-inaccessible space for mounting the filter housing. Essentially, the mechanics ordered a right-rear door panel and turned it over and installed it on the left side.

Seven buses were outfitted with the puraDYN oil bypass filter systems between October and December and are now operating. The eighth and last bus had a driveline failure in early December that damaged transaxle components. The replacement part was not off-the-shelf available, and the mechanics are waiting for delivery in late January 2003. This bus has the filter system mounted into the left-rear compartment, but the hoses are not yet connected to the oil pan. When the driveline is repaired, the mechanics will change the oil and finalize the filter installation. Photographs of installed filter systems on each of the three engine models are shown in Appendix A.

Oil Bypass System Operations and Evaluation

The operations part of the performance evaluation includes the following:

- Obtaining oil analysis samples of previously used dirty oil taken during filter system installation to characterize (baseline) the engine metal wear patterns before initiation of the oil bypass system performance evaluation
- Obtaining an oil analysis of the unused Shell Rotello-T oil to establish a baseline
- Replacing oil filters at the established intervals
- Oil analysis sampling of the test oil (Shell Rotello-T) during each filter replacement to track and document oil quality and engine metal-wear patterns and trends.

Pretest Engine Metal Wear Patterns

Previous oil analysis and engine metal-wear patterns documentation was not universal for the eight INEEL buses. However, there was sufficient information to allow the shop foreman and the test engineers to ensure each engine was suitable for the oil bypass system performance evaluation. When comparing the wear patterns of the eight buses to the entire fleet of 99 buses, they are much less severe due to the relative newness of the engines.

Shell Rotello-T Oil Baseline

At the beginning of the performance evaluation, oil samples are being sent to both laboratories for analysis. The main test data results of interest with virgin Shell Rotello-T oil are the:

- Oil additive concentrations
- Oil grade determination
- Total base number determination
- Viscosity values.

Reviewing the oil analysis reports from both laboratories shows that the values were fairly consistent, except for a 973-ppm difference in calcium levels. Additional samples were sent to both laboratories to repeat the new oil characterization to establish the new oil baseline. The new oil baseline will be completed in time for the next quarterly report. (For a complete discussion of the acceptable additive, grade, total base number, and viscosity levels, see Attachment 1).

Filter Replacement Schedule

The previous oil servicing schedule was to replace the diesel engine full-flow filter at each 12,000 mile oil change interval. The changing of the full-flow and oil bypass system filters is more complicated for the performance evaluation. With the puraDYN filter system in place, each diesel engine has two oil filters: the factory-installed full-flow filter that is normally replaced at each oil change interval and the new bypass filter. Both filters were new when the bypass filter system was installed. The new schedule includes the following:

- After the first 6,000 miles, both filters are replaced
- The bypass filter (the one-piece cotton filter element with additives insert) is then changed after each 12,000-mile increment.
- The full-flow filter is replaced at every 48,000-mile increment (after four 12,000 mile increments).

Oil Analysis Sampling during the Performance Evaluation

Oil analysis samples are taken at each filter replacement (initially at 6,000 and subsequently at 12,000 mile intervals) and sent to the two laboratories for analysis. If an abnormal value results, the laboratory staff immediately calls the INEEL Fleet Operations mechanic foreman and informs him of the abnormal condition. An abnormal condition would require values below the acceptable standard for items such as viscosity, total base number, or fuel/coolant contamination. The data from the analysis reports are compiled to document the oil quality and the engine metal-wear pattern profiles and trends. Over time and through analysis of the data, the project engineers and the mechanic foreman will monitor the profiles to identify when the oil is no longer acceptable. Appendix B is a chart showing the relationship between the oil analysis reports, the filter changing schedule, and changing the engine oil.

Aspects of Oil Analysis Reports

Each analysis report describes the condition of the oil and any reporting trends germane to the engine. The reports alert fleet personnel whenever the oil or an engine bearing or other engine part is out of the established range of acceptable wear. Other negative conditions can include:

- Oil degradation from the engine coolant or fuel
- Incorrect grade of lubricant
- Air-filter failure, allowing sand or dirt intakes
- Overextended or underutilized drain intervals.

The main parts of an oil analysis report include:

- Customer unit information: identification of the unit, manufacturer, and oil brand and type
- Sample data: laboratory test number, date of analysis, and miles on unit
- Physical properties, including viscosity and nonfuel contaminants, such as fuel, coolant, and water
- Oil degradation, including soot levels and total base number
- Spectrochemical results: metal wear components of the engine, for example, iron, chromium, and silicon, and oil additives, for example, calcium and phosphorus
- Recommendations relating to continued use of the oil—acceptable or unacceptable.

ECONOMIC ANALYSIS OF THE OIL BYPASS SYSTEM

As the performance evaluation continues, additional information will be generated that will quantify the performance of the puraDYN oil bypass system. Additional cost information will also be generated that will provide input for a life-cycle economic analysis. However, if some general assumptions are employed based on the knowledge gained so far from the performance evaluation, a very preliminary analysis can be performed to estimate the economics of the oil bypass system.

Assumptions

Each of the eight buses in the performance evaluation averaged about 60,000 miles during 2002, and it is assumed that they will continue to average about the same number of miles for the next few years. For this preliminary analysis, an approximately three-year period, a total of 186,000 miles, has been considered (see Appendixes C and D).

It is assumed that any oil used while the buses are in operation (from leaks or normal engine use) is the same, with or without the oil bypass system installed. The eight buses have record logs, so the drivers can note if oil is added.

The INEEL does not pay any direct oil disposal costs. An oil recycling company picks up the used motor oil for free, for volumes over 500 gallons. However, there should be some costs to the INEEL for handling and storing this large volume of oil. Additional costs are incurred contacting and escorting the oil recycler when at the INEEL. These costs will be investigated and added to future analysis.

For this analysis, the costs for the initial oil and full flow filters in buses with the oil bypass system and in buses without the bypass systems is considered equal.

No reductions in facility costs are included in this analysis. If the oil bypass system proves feasible, shop time should be reduced, and this should correlate to reductions in facility and labor costs, but this assumption is too tenuous to be included at this point.

It is assumed that oil analysis is performed similarly for either option, so this is not modeled.

All costs are in 2003 dollars.

This is a very preliminary cost comparison. It should not be considered a final economic analysis for either type of oil filtration method.

Status Quo Traditional Oil Changing Costs

After 186,000 miles, the total cost for the labor and parts required for the oil and changes totals \$1,532 per bus (see Appendix C).

Bypass Filter Oil Changing Costs

After 186,000 miles, the total cost for the labor and parts required for the oil bypass system totals \$1,382 per bus (see Appendix D).

Cost Comparison Discussion

A comparison of the cumulative costs of the traditional oil filter and bypass filter systems shows that the bypass filter system has lower life-cycle costs starting at about 150,000 miles (see Figure 3). However, not all costs are known at present for either option. This analysis is very preliminary, as the test is in its infancy and future costs are as yet poorly identified. In addition, no costs are currently known for storing and disposal of the used oil. As this evaluation proceeds, the practices for handling the used oil will be better defined and costed. These oil disposal costs will likely result in an earlier payback period than 150,000 miles for the oil bypass system. Note that the time necessary to install the bypass systems on the three buses with the 50 Series engines includes installation of the new access door necessitated by the location of the onboard restrooms. The expected early payback period highly depends on the performance of the oil bypass systems and the continued satisfactory condition of the unchanged oil.

It is estimated that during the 186,000-mile analysis, about 132 gallons (528 quarts) of oil will be saved per bus. While the cost to purchase the oil is included in the analysis, the disposal costs are not fully explored for either the INEEL recycling method or for the traditional disposal method of paying a third party to remove the oil.

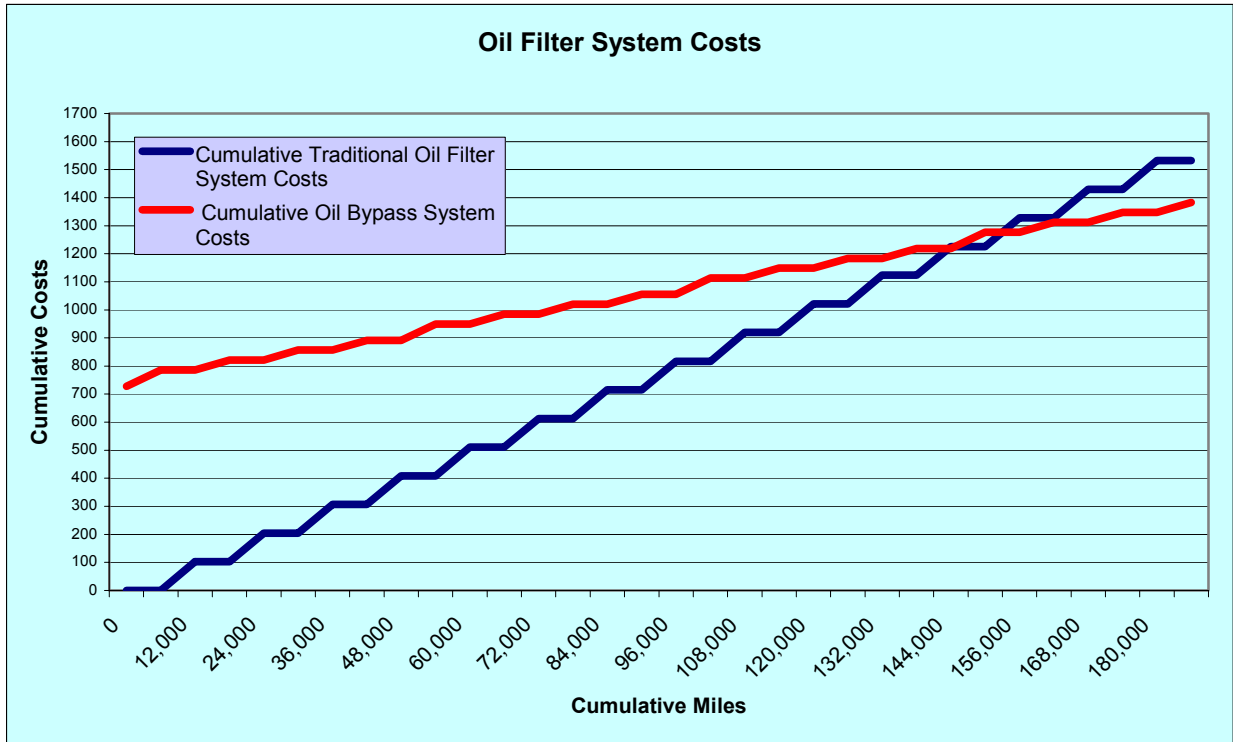


Figure 3. Preliminary analysis of cumulative costs per mile per bus for the traditional oil-filter and bypass filter systems.

CONCLUSIONS

This very preliminary economic analysis suggests that the oil bypass filter system has very real potential to reduce oil use, generation of waste oil, and other oil-change-related costs. This performance evaluation activity will continue operating the buses and gathering empirical oil analysis data to validate the concept of extended oil use as part of the oil bypass filter system. The costs associated with handling and depositing used oil will also be quantified.

Because a large number of light-duty vehicles are in use throughout the DOE complex, expanding the performance evaluation to include six to eight light-duty vehicles at the INEEL is intended. Several paraDYN systems have been ordered to help identify engine compartment space limitations in various light-duty vehicles as part of the process to select which vehicles to add to the evaluation.

Appendix A
Photographs of Installed puraDYN Systems

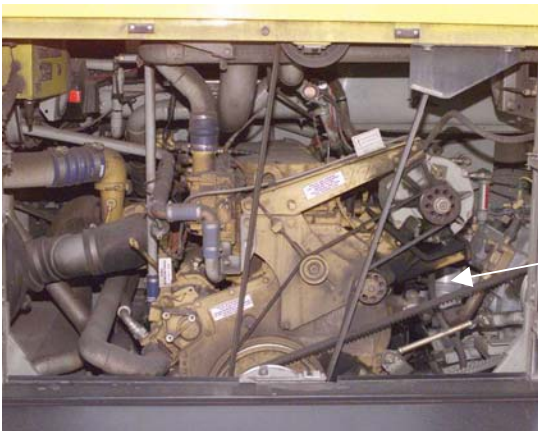
APPENDIX A

Photographs of Installed puraDYN Systems

The photographs show the installed puraDYN systems in the INEEL buses for each of the three bus engine types.



Figure 4. Photograph of Caterpillar engine compartment on bus 450.



Arrow points to the filter system rear view

Figure 5. Close-up photograph of the Caterpillar engine compartment.



Figure 6. Photograph of Caterpillar engine filter system through side engine compartment door.



Figure 7. View of engine and filter system on a bus with a Series 50 Detroit Diesel engine.



Figure 8. Close-up of filter system in rear engine compartment for a bus equipped with a Series 50 Detroit Diesel engine. The doors were installed to provide access space for the filter.



Figure 9. View of the bypass filter in the passenger-side engine compartment of a bus with a Series 60 Detroit Diesel engine.



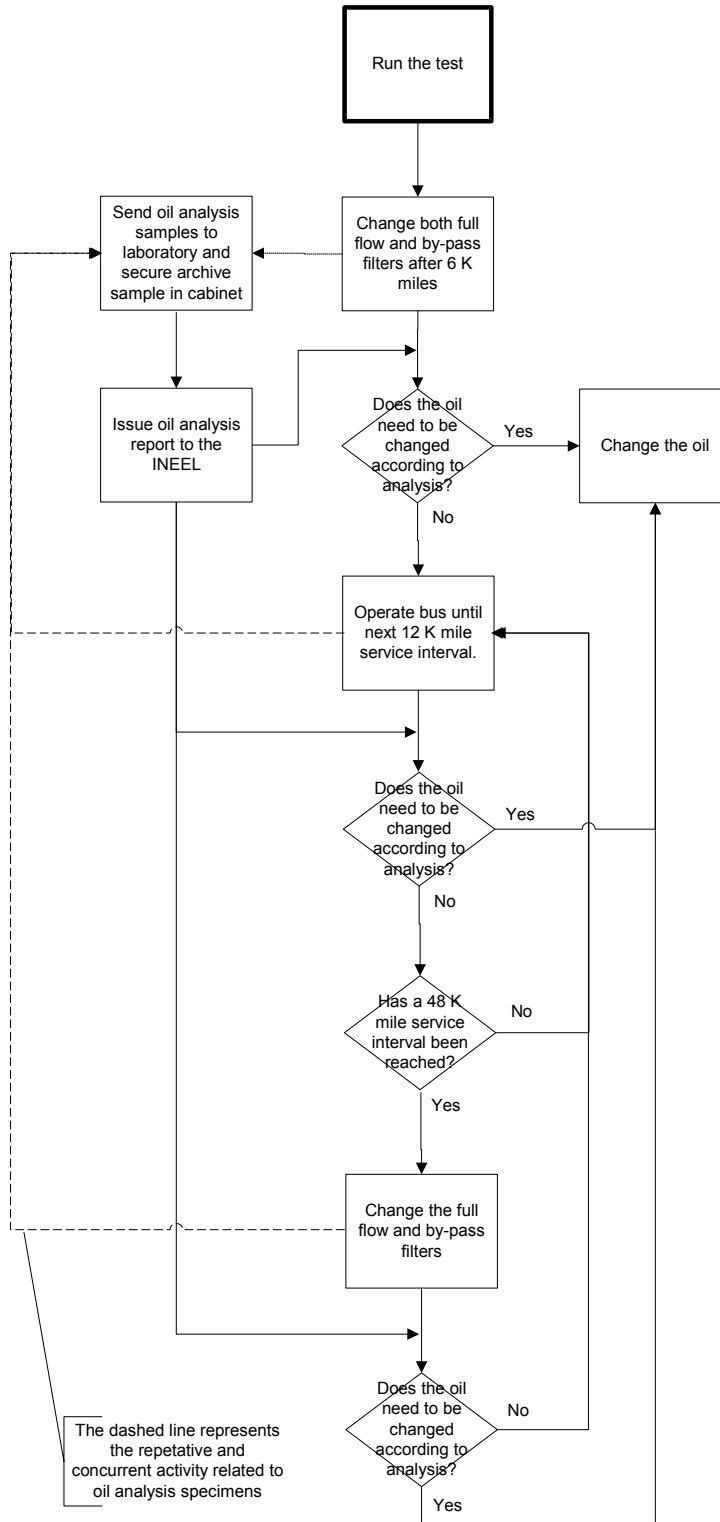
Figure 10. INEEL mechanic installing an oil bypass filter on a bus with a Series 60 Detroit Diesel engine.

Appendix B

Relationship between the Oil Analysis Reports, the Filter Changing Schedule, and Changing the Engine Oil

APPENDIX B

Relationship between the Oil Analysis Reports, the Filter Changing Schedule, and Changing the Engine Oil



APPENDIX C

Cost Analysis of the Traditional Oil Filter System

APPENDIX C

Cost Analysis of the Traditional Oil Filter System

Traditional Oil Changing Costs								
Oil Change Intervals	Cumulative Bus Mileage	Full Flow Filter Cost	Full Flow Filter Change Labor Cost (1)	Oil Cost per change (2)	Oil Change Labor Cost (3)	Total Cost per Oil "Event"	Cumulative 6,000 mile Intervals	Cumulative Costs at 6,000 mile intervals
	0						0	0
							6,000	0
12,000	12,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	12,000	\$102.13
							18,000	\$102.13
12,000	24,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	24,000	\$204.26
							30,000	\$204.26
12,000	36,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	36,000	\$306.39
							42,000	\$306.39
12,000	48,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	48,000	\$408.52
							54,000	\$408.52
12,000	60,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	60,000	\$510.65
							66,000	\$510.65
12,000	72,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	72,000	\$612.78
							78,000	\$612.78
12,000	84,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	84,000	\$714.91
							90,000	\$714.91
12,000	96,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	96,000	\$817.04
							102,000	\$817.04
12,000	108,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	108,000	\$919.17
							114,000	\$919.17
12,000	120,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	120,000	\$1,021.30
							126,000	\$1,021.30
12,000	132,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	132,000	\$1,123.43
							138,000	\$1,123.43
12,000	144,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	144,000	\$1,225.56
							150,000	\$1,225.56
12,000	156,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	156,000	\$1,327.69
							162,000	\$1,327.69
12,000	168,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	168,000	\$1,429.82
							174,000	\$1,429.82
12,000	180,000	\$8.60	\$14.23	\$36.70	\$42.60	\$102.13	180,000	\$1,531.95
							186,000	\$1,531.95
Totals		\$129.00	\$213.45	\$550.50	\$639.00	\$1,531.95		

(1) \$56.90 labor rate X 0.25 hours
(2) 8.8 gallons x \$4.17 current cost of America's Choice (estimated oil cost)

APPENDIX D
Cost Analysis of the Oil Bypass Filter System

APPENDIX D

Cost Analysis of the Oil Bypass Filter System

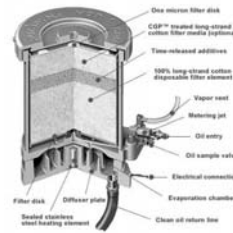
puraDYN Oil Bypass System Costs									
System Action Intervals (1) (2)	Cumulative Bus Mileage	Bypass Filter Element Cost	Element Change Labor Cost (3)	Full Flow Filter Cost	Filter Change Labor Cost (3)	Initial Bypass System Parts and Labor Costs(4)	Total Cost per Oil "Event"	Cumulative 6,000 mile Intervals	Cumulative Costs at 6,000 mile intervals
0	0					\$728.00	\$728.00	0	\$728.00
6,000	6,000	\$21.00	\$14.20	\$8.60	\$14.20		\$58.00	6,000	\$786.00
12,000	18,000	\$21.00	\$14.20				\$35.20	12,000	\$786.00
								18,000	\$821.20
								24,000	\$821.20
12,000	30,000	\$21.00	\$14.20				\$35.20	30,000	\$856.40
								36,000	\$856.40
12,000	42,000	\$21.00	\$14.20				\$35.20	42,000	\$891.60
								48,000	\$891.60
12,000	54,000	\$21.00	\$14.20	\$8.60	\$14.20		\$58.00	54,000	\$949.60
								60,000	\$949.60
12,000	66,000	\$21.00	\$14.20				\$35.20	66,000	\$984.80
								72,000	\$984.80
12,000	78,000	\$21.00	\$14.20				\$35.20	78,000	\$1,020.00
								84,000	\$1,020.00
12,000	90,000	\$21.00	\$14.20				\$35.20	90,000	\$1,055.20
								96,000	\$1,055.20
12,000	102,000	\$21.00	\$14.20	\$8.60	\$14.20		\$58.00	102,000	\$1,113.20
								108,000	\$1,113.20
12,000	114,000	\$21.00	\$14.20				\$35.20	114,000	\$1,148.40
								120,000	\$1,148.40
12,000	126,000	\$21.00	\$14.20				\$35.20	126,000	\$1,183.60
								132,000	\$1,183.60
12,000	138,000	\$21.00	\$14.20				\$35.20	138,000	\$1,218.80
								144,000	\$1,218.80
12,000	150,000	\$21.00	\$14.20	\$8.60	\$14.20		\$58.00	150,000	\$1,276.80
								156,000	\$1,276.80
12,000	162,000	\$21.00	\$14.20				\$35.20	162,000	\$1,312.00
								168,000	\$1,312.00
12,000	174,000	\$21.00	\$14.20				\$35.20	174,000	\$1,347.20
								180,000	\$1,347.20
12,000	186,000	\$21.00	\$14.20				\$35.20	186,000	\$1,382.40
	Totals	\$336.00	\$227.20	\$34.40	\$56.80	\$728.00	\$1,382.40		

(1) 6,000: The first filter change-out interval with the PuraDYN filter system is half of the standard interval.
(2) 48,000: The change-out interval of the full flow filters is 48,000 miles. Required at 54k, 102k, 150k cumulative miles
(3) \$56.90 labor rate X 0.25 hours
(4) Includes initial bypass filter element cost in system cost of \$302, installation kit cost \$121, 5 hours labor X \$56.90

ATTACHMENT 1
PURADYN OIL BYPASS FILTRATION SYSTEM EVALUATION TEST
PLAN

Transportation Technologies & Infrastructure Department

PURADYN OIL BYPASS FILTRATION SYSTEM EVALUATION TEST PLAN



October 2002

Reviewed:	_____	_____
	INEEL Fleet Maintenance Supervisor (Thomas)	Date
Reviewed:	_____	_____
	INEEL Bus & Heavy Equipment Foreman (Murdock)	Date
Reviewed:	_____	_____
	INEEL Fleet Maintenance Department Manager (Bullock)	Date
Approved:	_____	_____
	INEEL Central/Idaho Falls Facilities Director (Winn)	Date
Reviewed:	_____	_____
	INEEL Test Engineer (Zirker)	Date
Reviewed:	_____	_____
	INEEL Project Manager (Francfort)	Date
Approved:	_____	_____
	INEEL TT&I Department Manager (Murphy)	Date

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PURADYN OIL BYPASS FILTRATION SYSTEM EVALUATION TEST PLAN

1. PURPOSE AND APPLICABILITY

Activities conducted as part of this multi-year test program include the installation, operation, and evaluation of a commercial oil bypass filter technology from PuraDYN Filter Technologies Incorporated, of Boynton Beach, Florida. The oil bypass technology will initially be evaluated on eight buses in fleet use at the Idaho National Engineering and Environmental Laboratory (INEEL). The eight buses use three different models of four-cycle diesel engines.

The program activities will include an analysis of the economic benefits of the commercial oil bypass filtration system technology on a per vehicle basis as well as on a fleet basis. In addition, fleets in the DOE complex will be surveyed to identify the types of vehicles in use and the approximate miles driven to determine the petroleum reduction potential complex-wide if an oil bypass filtration system were used. This complex-wide analysis will include identifying the potential economic benefits complex-wide.

Published reports state that oil bypass filtration systems provide multiple economic and petroleum-use savings, including:

- Less dependency on foreign oil
- Less oil disposed as waste products
- Lower oil disposal costs
- Less downtime of equipment
- Reduced vehicle maintenance costs
- Quick return on investment
- Less oil related environmental issues—spills, drinking water contamination, and waste oil handling.

The INEEL Bus Fleet Operations will be used as the initial test bed for this evaluation:

- The fleet has eight buses with three models of modern four-cycle diesel engines currently in use, with relatively low miles per engine (99 buses total in the INEEL fleet).
- The eight buses all operate on similar routes—about 150 miles per day with both city and highway travel.
- The buses have had consistent maintenance.

Follow-on work will include identifying and evaluating other candidate test vehicles. The candidate vehicles will be evaluated to determine how representative they are in relation to vehicle use within the entire DOE complex and if they accumulate sufficient mileage or use-hours requiring frequent oil changes.

1.1 Activities to be Performed Under this Test Plan

There are four main activities performed during this test program. These activities with subtasks are shown in the following graphic (Figure 1).

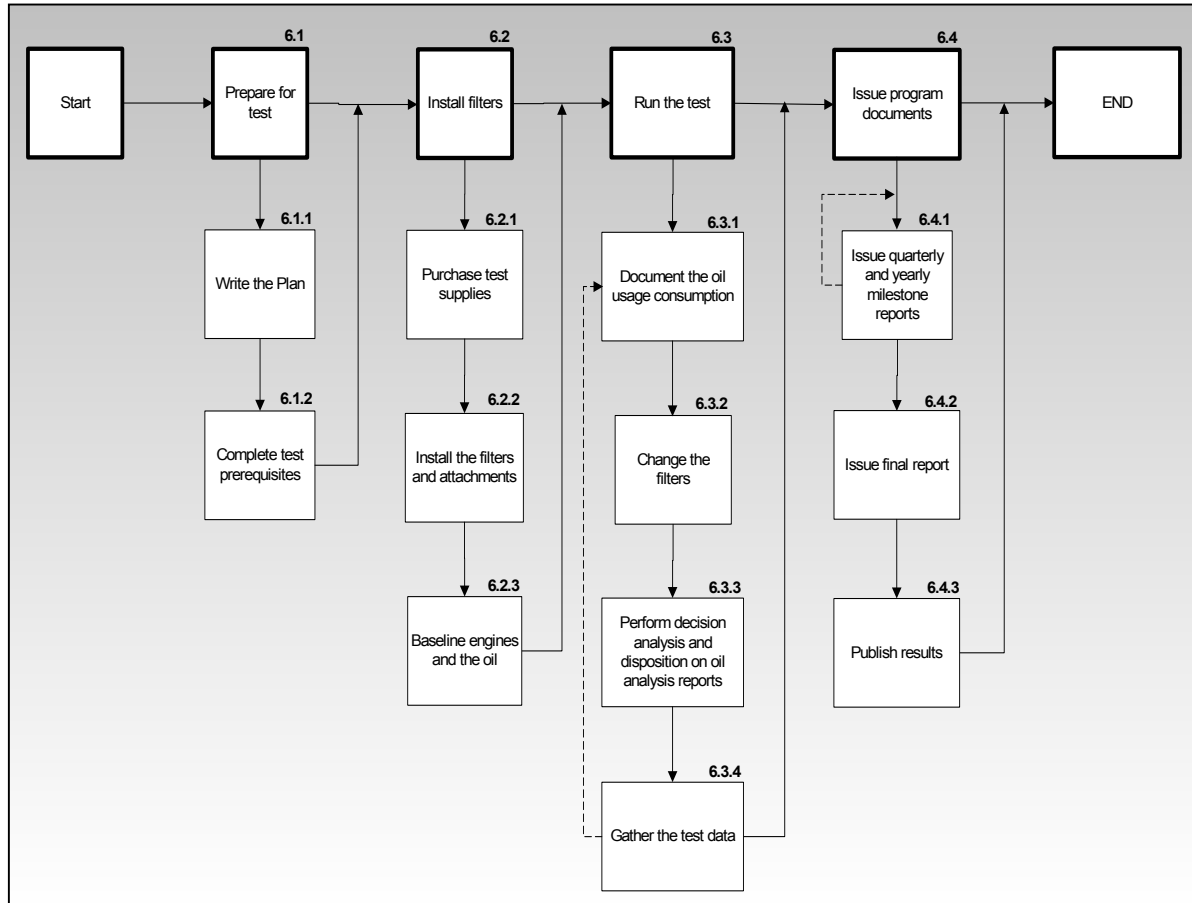


Figure 1. Overview of the four main Testing Program tasks and the respective subtasks. The tasks and subtasks are discussed in detail in Section 6 by task number.

1.2 Features of the PuraDYN Filtration System

The premise of the PuraDYN bypass filtration system is that oil does not wear out; it gets dirty with combustion products and liquids, and loses its acid reducing capacity. With regular filter changes, the bypass filtration system keeps the engine oil clean, extends engine life and reduces operating costs by greatly extending oil change intervals. Other reported features of the PuraDYN filtration system include:

- It has no moving parts.
- It continuously cleans the lubricating oil by reducing solid contaminants down to 0.25 micron.
- It removes liquid contaminants (fuel and coolant) from the lubricating oil with a heated evaporation chamber in the filtration system housing where any fuel and coolant are evaporated and vented.

- Through a time-release feature in the bypass replacement filter, additives are released to the lubricant to maintain a high total base number (TBN) to neutralize any acid build up.
- It cleans the lubricant at six to eight gallons per hour.
- The bypass filter system can be installed in two hours.
- The subsequent bypass filter changing takes minutes.
- Each bypass filter system costs \$325, each installation kit costs \$90.00 and each replacement bypass filter cartridge costs \$21.00.

2. REFERENCES

- PuraDYN Installation Manual
- Instructional Installation Video

3. EQUIPMENT AND HARDWARE REQUIREMENTS

- The necessary personnel, tools, equipment, and facilities will be supplied by the INEEL Fleet Maintenance Heavy Vehicle Transportation Center for installation, maintenance, and servicing functions.
- Ten model PFT-40 PuraDYN filters systems (two backup systems) with installation kits, spare parts, and 112 replacement filter cartridges for the three-year test.
- Eight low mileage four-cycle diesel engines operating in INEEL buses.
- Three 55-gallon drums and 100 one-gallon jugs of Shell, Rotello, 15w-40 oil.
- Forty-eight full-flow filters—five for the Caterpillar engine and 35 for the Detroit Diesel engines.

4. PREREQUISITES AND PRE-TEST PREPARATION

- Conduct all required safety evaluations by Fleet Maintenance safety personnel to ensure all hazards have been identified and mitigated.
- Establish and maintain safety control procedures, job safety analyses, and work control documents.
- Establish the installation locations of the bypass filter housings within the bus engine compartments.
- Identify and define all tasks, performers, and deliverables of the test.
- Order and stage all filter systems, filter cartridges, installation supplies, engine oil, and spare parts in the Fleet Maintenance Facility.
- Pre-mark (or flag) the maintenance record database of the selected test buses with the test details and the testing instructions.
- Review and approve (signed off) the test plan prior to installing the filters.
- Detail the basic scope of the test and emphasize that it is a DOE-HQ sponsored test in a meeting with the appropriate bus fleet personnel

- Ensure the INEEL mechanics and foreman review the installation manual and view the instructional installation video.
- Install warning signs within the engine compartment alerting all fuelers, drivers and mechanics to any bypass filter system burn hazards, the non oil-change status of the bus, and oil-use logging requirements.
- Instruct the fuelers and drivers to use only the specified test oil when adding oil during their inspections and that they are to log the approximate volume of oil added.
- Instruct the mechanics to use only the unique test oil when adding oil during the filter changes and that they are to log to approximate volume of oil added.
- Provide oil use logs sheets for each of the buses and the oil storage area.
- Instruct the mechanics and shop foremen on the chain-of-custody requirements when capturing, submitting and archiving the oil analysis samples and containers.
- Install a lockable chemical cabinet for holding in-process and archived oil specimens.
- Convene and complete a readiness self-assessment prior to installation of the bypass filter systems to ensure manpower, safety, management, and equipment/supply issues have been addressed and are adequate for the test.

5. BASELINE OF THE ENGINES AND OIL ANALYSIS

Table 1 details the buses, bus engines, and oil.

Table 1. Test engine types and descriptions.

Bus No. ¹	Engine ²	Cyl	Cubic inches	Horse Power	Oil Cap (quarts)	Oil	Engine Install Date	Engine Mileage ³	Est. Annual Mileage
73425	Series 50	4	518	250	28	15-40	10/1/96	302,000	29,000
73432	Series 50	4	518	250	28	15-40	10/1/96	416,000	54,000
73433	Series 50	4	518	250	28	15-40	10/1/96	193,000	17,000
73446	Series 60	6	777	400	40	15-40	12/1/98	110,000	46,000
73447	Series 60	6	777	400	40	15-40	12/1/98	91,000	21,000
73448	Series 60	6	777	400	40	15-40	12/1/98	141,000	32,000
73449	Series 60	6	777	400	40	15-40	12/1/98	101,000	28,000
73450	Model 310	6	628	350	38	15-40	1/8/01	85,000	69,000

1. All of the buses are MCI coaches and the engines are tracked and maintained by the bus number.
2. The series 50 and series 60 are Detroit Diesel engines, and bus 73450 has a Caterpillar engine.
3. The three series 50 engines were installed as part of a research program with Detroit Diesel. The remaining 5 engines were installed as original equipment with each new bus coach.

5.1 Oil Analysis and Records

Oil analysis specimens are taken during each oil change in the following manner:

1. A sample of dirty or used oil is captured in a 120 cc sample container via the oil-sampling valve.
2. This container is tagged with a label containing information germane to the oil, bus engine, and customer.
3. The sample container is inserted into a shipping container and shipped to the oil analysis laboratory.

Photographs of the containers and copies of the labels are shown in Appendix A. The chain of custody of the oil, containers, labels and the analysis results is paramount in this test.

The product of an oil analysis is the oil analysis report. The report details:

- Engine metals
- Viscosity
- Fuel and coolant contaminants
- TBN
- Additive constituents
- Recommendations

General values or limits of an oil analysis report for a new engine are shown in Appendix B. It should be noted that the wear pattern of each engine varies, but the most important flag to engine or lubrication problems is a significant deviation to an established profile. An independent oil analysis laboratory currently provides this service to the INEEL. For this program, the engine oil profiles will also be tracked at the INEEL.

A typical oil analysis report is shown in Appendix C. A detailed explanation of all aspects of oil analysis is located in Appendix D.

The oil analysis laboratory recommended by PuraDYN and, coincidentally, currently used by the INEEL Fleet Operations is CTC Analytical Services of Phoenix, Arizona. CTC will continue to be used for oil analysis and a second oil analysis laboratory (Ana Laboratories of Bellmawr, NJ) will provide a second reference of the oil analysis test results at least until it is confirmed that the CTC results are accurate and consistent.

6. BYPASS FILTRATION SYSTEM - TESTING PROGRAM

- The high level tasks and subtasks of the testing program are shown in Figure 1 and discussed in detail in this section. The high level tasks include:
- Prepare for Test (Section 6.1)
- Install Filters and Initial Service of the Engines (Section 6.2)
- Run Test (Section 6.3)
- Issue Program Documents (Section 6.4)

6.1 Prepare for Test

6.1.1 Generate Test Plan.

Generating the test plan includes interacting with selected stakeholders to identify the test requirements, articulating the requirements, defining the interfaces between the stakeholders, and obtaining final agreement or sign-off on the test plan.

6.1.2 Complete Test Prerequisites

The prerequisites are listed in section 4 (Prerequisites and Pre-Test Preparation) and shall be completed prior to installation of the filter systems.

6.2 Install PuraDYN Filter System and Initial Service of the Engines

6.2.1 Purchase Test Supplies.

The supplies are listed in (Section 3 Equipment and Hardware Requirements) and shall be procured prior to the installation of the filter system.

6.2.2 Install the Filters and Attachments (Hoses and Connections)

Refer to the PuraDYN Installation Manual for detailed graphics and written instructions on the installation of the filter housing, connecting hoses, inserting the filter cartridge, and servicing the components. The installation of the bypass filter system shall be performed after the engine has been serviced with the test oil (see Section 6.2.3).

Once the installation is complete, the operation of the PuraDYN Filter System shall be verified. Once the filter cartridge is placed into the filter housing, there are two steps to ensure the filter is operational. These are:

1. Verify metering jet is not plugged. Open oil sample valve, which is down stream from the metering jet fitting. If oil flows this confirms the metering jet is not plugged.
2. Verify heated evaporation chamber in the filter housing is operational. If the heated evaporation chamber is functioning, the heating element will draw 12.5 amperes (12 volt system). The heating element causes the filter housing to have a near constant 200 degree F temperature.

6.2.3 Baseline Engines and Oil

Oil samples will be taken to document the initial oil-in-the-engine profile and the oil-in-the-can profile. This oil profiling includes the following tasks:

- Take three used oil analysis samples during oil changing service and label the containers
- Submit one used oil sample to each of the two oil analysis laboratories.
- Secure one used oil analysis specimens into the archive cabinet
- Change the full flow filter—use the filters selected for the test that are in the storage area
- Obtain engine oil from the oil storage area and log the quantity used on the log sheet.
- Replace the engine oil with Shell Rotello, 15w-40 oil
- Obtain three analysis samples of the new oil and label the containers

- Submit one new oil sample to each of the two oil analysis laboratories
- Secure one new oil analysis specimens into the archive cabinet
- Install the bypass filter system
- Complete the Work Order.

6.3 Run Test

The testing activities are divided into four parts:

- Document the daily oil usage consumption (Section 6.3.1)
- Change the filters (Section 6.3.2)
- Analyze oil analysis reports (Section 6.3.3)
- Gather the Test Data (Section 6.3.4)

6.3.1 Document the Daily Oil Usage Consumption

The driver and the fueler check the bus oil level daily when the bus is fueled. A one-gallon container of oil and an Oil Usage Log are located in the storage compartment of each bus. When oil is needed, only the test oil, Shell, Rotello, 15w-40 is to be used and the amount added is entered on the Oil Usage Log sheet (Appendix E).

6.3.2 Change the Filters

The Changing the Filters flow diagram (Appendix F) details the sequential and repetitive steps and decision boxes in changing the filters, capturing the oil analysis samples, and analyzing the oil analysis results during the test. The PuraDYN literature defines the filter replacement schedule recommendations. These recommendations are included in the Extended Oil Drain Schedule (Appendix G) and reflected in the Changing the Filters flow chart (Appendix F).

6.3.3 Analyze Oil Analysis Reports

The shop foreman reviews the oil analysis reports and completes the decision analysis process by documenting the unit number, oil analysis sample date, miles on oil and disposition (yes – continue oil use or no - change the oil). When a negative disposition occurs, the test engineer and the maintenance supervisor are notified.

A decision analysis is performed when the shop foreman reviews each oil analysis report by following the Decision Analysis and Disposition Chart (Appendix H) to determine the fitness of the oil for continued use. The chart diagram defines the decision steps related to each data aspect of the oil analysis report. The decision steps are based on:

- The elevated levels of metal wear of engine components in parts per million (ppm)
- The elevated percent levels of fuel and coolant contaminants
- The reduction of the TBN
- The reduced levels of oil additive constituents
- The reduced viscosity levels
- The significant changes in any analysis trend.

6.3.4 Gather the Test Data

The test engineer gathers the following test data from the various performers:

- Oil Usage Logs
- Work Orders
- Oil Analysis Reports
- Decision Analysis and Disposition Charts

6.4 Issue Program Documents

Issuing program reports is divided into three parts:

- Quarterly and yearly milestone reports (Section 6.4.1)
- Final Report (Section 6.4.2)
- Publish Results (Section 6.4.3)

6.4.1 Quarterly and yearly Milestone Reports

Quarterly status reports will be issued, including:

- Total miles traveled per bus
- Number of filter changes per bus
- Total gallons of oil usage per bus
- Trends reported in the oil analysis reports.
- Initial analysis of economic tradeoffs such as oil use and disposal reductions versus system installation costs.
- The yearly milestone reports shall rollup the quarterly report data and provide a year-to-date cost savings/cost avoidance analysis.

6.4.2 Final Report

At a minimum, the final report to DOE shall include:

- Compilation of the quarterly status and yearly milestone reports
- Documentation of the PuraDYN filter system performance
- Compilation of the comprehensive life-cycle costs benefits
- Evaluation of the cost effectiveness and return of investment for installing PuraDYN filter system within the complete INEEL bus fleet.

6.4.3 Publish Results

The test program activities will be presented in DOE publications, selected professional or trade journals, and at industry conferences.

7. SAFETY CONCERNS AND PRECAUTIONS

- There are no unique safety concerns or precautions with the installation of the PuraDYN filter system beyond the normal hazards related to heavy mechanic work.
- There is one potential hazard with the servicing of the bypass filter. The evaporation chamber (inside of the filter where fuel and water are evaporated) is heated causing the outside surface of the filter housing to be approximately 200 degree F. The housing is pre-labeled, at the factory, “HOT”. Also, there is a sign posted where the filter is attached that states the filter housing is hot. With training and warning signs, the mechanics shall avoid this hazard as they do other hotter engine parts such as exhaust manifolds
- The Fleet Operations safety personnel have reviewed this test plan (maintenance and servicing activities) and the installation manual, and found no unique safety concerns
- The mechanic shall have tailgate training on the hazards of maintenance and servicing the filter systems.

8. TEST DATA REPORTING REQUIREMENTS

The buses and the engines all have regular maintenance and servicing. A matrix of the general tasks, performers and test data deliverables relating to maintaining and servicing are shown in Table 2.

Table 2. General Tasks, Performers and Deliverables

Task	Performer	Deliverable	Notes
Add oil as needed during daily pre-trip check	Driver	Record volume on Oil Usage Log	The drivers are required to perform a pre-trip inspection. Part of their pre-trip inspection is to check the oil and add oil as needed.
Add oil as needed during bus fueling	Fueler	Record volume on Oil Usage Log	The bus fuelers are required to perform an engine oil check during fueling.
Receive alert for service notice	Shop Foreman	Work Order	The alert for service request relating to lubrication occurs at 12,000-mile intervals. The only exception is at the beginning of the test when the first service is at 6,000 miles; afterward it is at 12,000-mile intervals. A Work Order is generated at each alert.
Turn in service documents	Mechanic	Work Order	Completed Work Order is returned to shop foreman when the work is finished.
Receive oil analysis report	Shop Foreman	Oil analysis report	The oil analysis report is issued by the oil analysis laboratory with each 12,000-mile service. The oil analysis laboratory sends the report directly to the Shop Foreman.
Perform decision analysis on oil analysis report	Shop Foreman	Decision Analysis and Disposition Chart	The Shop Foreman uses the Decision and Analysis and Disposition Chart as a checklist when reviewing the oil analysis reports and to document the continued use or change oil disposition.

There are several specific tasks performed during the filter replacement and servicing that generates test data. Performance of these tasks is documented on the Work Order. Details of these tasks are listed in Table 3.

Table 3. Specific Tasks, Performers and Deliverables

Task	Performer	Deliverable	Notes
Capture used oil analysis samples in labeled specimen bottles	Mechanic	Three filled 120 cc bottles of used oil.	Capture three identical 120 cc specimens of used oil and label the specimen and shipping containers during servicing - two specimens for oil analysis and one for archiving. The oil analysis specimens are taken at every 12,000-mile interval. The only exception is at the beginning of the test when oil analysis specimens are first taken at 6,000 miles.
Capture new oil analysis samples in labeled specimen bottles	Mechanic	Three filled 120 cc bottles of new oil.	Capture three identical 120 cc specimens and label the specimen and shipping containers during servicing - two specimens for oil analysis and one for archiving. This activity is performed only once during the test when new oil is added to the engines. This provides a baseline of the new oil.
Verify metering jet is not plugged	Mechanic	Indicate status on Work Order form	The metering jet feeds oil into the filter housing and can become plugged. Open the oil sample valve, which is located downstream from the metering jet. Flowing oil indicates that the jet is not plugged.
Replace by-pass filter	Mechanic	Indicate oil full flow and/or bypass filter(s) replacement on Work Order form	Confirm filter(s) replacement on Work Order. By-pass filter cartridge is replaced at every service interval. Full flow filter is replaced at first 6,000-mile interval and every 48,000 miles thereafter.
Verify heated evaporation chamber is operational	Mechanic	Indicate if heating element is operational on Work Order form	Validate that the filter housing is drawing 12.5 amperes (12 volt system).
Mail and archive specimen bottles	Shop Foreman	Ships and archives specimens.	Shop Foreman mails specimen bottles. The archived specimen bottles are secured in a storage cabinet as backup specimens.

9. ANTICIPATED RESULTS

- Published data suggests PuraDYN customers have seen cost savings up to 90% on oil purchases and oil disposal due to greatly extended oil change frequencies. Cost savings captured by extending the oil change frequency includes those identified in Section 1, plus other economic benefits of less dependency on foreign oil and less oil-related environmental issues—spills, drinking water contamination, and waste oil handling/disposal.
- The INEEL would immediately avoid using 30 to 40 quarts of oil with every servicing on every bus engine with this new filter system.
- With the oil use reduction, there is concurrently 30 to 40 quarts of oil that does not have to be disposed of at each oil change.
- Vehicle maintenance requirements should decrease and utilization should increase.
- The life cycle cost savings of oil changes should be greater than any additional costs associated with the bypass filter system.

10. CONTACT PERSONS

The test program point of contact list is show in Table 4.

Table 4. Test Plan contact list.

Order	NAME	Email	ORG.	PHONE
1	Larry Zirker	Zirklr@inel.gov	*BBWI / INEEL test engineer	208-526-0152
2	Ted Thomas	tat@inel.gov	BBWI / INEEL Fleet Maintenance Supervisor	208-526-7247
3	Gary Murdock	gm5@inel.gov	BBWI / INEEL Bus & Heavy Equipment Foreman	208-526-2248
4	Jim Francfort	francfje@inel.gov	BBWI / INEEL Field Operations Program Manager	208-526-6787
5	Kirt Bullock	krb@inel.gov	BBWI / INEEL Fleet Maintenance Department Manager	208-526-2252
6	Tim Murphy	murphtc@inel.gov	BBWI / INEEL TT&I Department Manager	208-526-0480
7	Mike Anderson	andersmr@id.doe.gov	DOE-ID Project Manager	208 526-7418
	Kevin Kroger	kkroger@puradyn.com	**PuraDYN Chief Operations Officer	248-931-2644
	Frank Lotz	flotz@puradyn.com	PuraDYN Product Engineering	561-547-9499

*BBWI – Bechtel BWXT Idaho, LLC is the prime contractor at the INEEL.

**PuraDYN – PuraDYN Filter Technologies Company is the manufacturer of filter system to be tested.


APPENDIX A

OIL ANALYSIS SHIPPING CONTAINERS AND LABELS



CTC House (M)	TST PKG:
BECHTEL BWXT IDAHO LLC (BWI)	
Cust No: 16170325 SCOVILLE, ID	
Unit ID: _____	
2ndID: _____	
Desc: _____	Comp Type: _____
Time/Miles on Unit _____ on Oil: _____	
Oil Added: _____ Gal/Qts	Oil Changed: Y/N
Date Taken: _____	PKG: _____



From: _____ _____ _____	<small>Please place postage or UPS stamp here</small>
<div style="background-color: blue; color: white; padding: 5px; text-align: center;">EXPERT LUBRICATION AND FUEL ANALYSIS SERVICES Saves Money and Down Time! • Engines • Transmissions • Hydraulic Systems • Turbine Compressors • Gear Box</div>	To: Phone: (800) 445-7930 CTC Analytical Services Inc 101 WEST MOHAVE 85003-2741 PO BOX 29074 PHOENIX AZ 85038-9074
<small>CTC-PHX Rev. 1/88</small> 	

APPENDIX B

VALUE LIMITS FOR OIL ANALYSIS REPORTS T

The following wear metals values are general limits for a first time generic engine sample that does not have any history.

NOTE: These values are not absolute since each engine is unique, and it takes three or more sample reports to establish a trend of the actual engine wear metal values.

- Iron = 100 ppm
- Chromium = 12 ppm
- Lead = 30 ppm
- Copper = 30 ppm
- Tin = 18 ppm
- Aluminum = 18 ppm
- Nickel = 10 ppm
- Silicon = 20 ppm or 20 ppm greater than that of the new oil (if the reference is on file).

The limits for viscosity would be based on the SAE grade that is specified:

- SAE 30 has a range of 9.29 cst to 12.49 cst
- SAE 40 has a range of 12.50 cst to 16.29 cst
- SAE 50 has a range of 16.30 cst to 21.89 cst

Fuel-Soot

- 3.0% is the flagging point

Total Base Number

- 3.0 (mgKOH/mL) or below for TBN is considered low.

APPENDIX C

TYPICAL OIL ANALYSIS REPORT

CTC Analytical Services

CUSTOMER NO.: 16170325
UNIT NO.: 70372
DESCRIPTION: ENGINE
END USER: GARY MURDOCK
BECHTEL BWXT IDAHO LLC(BBWJ)
END USER LOCATION: IDAHO FALLS, ID 83415-4103

**101 WEST MOHAVE
PHOENIX, AZ 85003-2741
(800) 445-7930, FAX (602) 252-4839**

MAKE:
MODEL:
OIL BRAND:
OIL TYPE:
SERIAL NO.:
FUEL TYPE: DIESEL

NO. COPIES 1

SAMPLE DATA

LAB#	SAMPLE DATE	TIME ON OIL
126575	07/09/2001	12000
NORMAL	07/18/2001	

SPECTROCHEMICAL ANALYSIS (ppm)

IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	Vanadium	POTASSIUM	FUEL	VIS @ 40 C	VIS @ 100 C	WATER (%)	SOOT/SOULS	GLYCOL
38	2	4	3	2	2	0	0	3	54	0	162	2942	0	921	1197	9	0	0	0	<1	N/A	12.37	0	1.3	NEG

ADDITIONAL TESTS

LAB# 126575
TEN 7.5

GRAPHICAL ANALYSIS

No History to Graph

LAB# 126575

Key
A: Abnormal C: Critical

ANALYSIS RECOMMENDATIONS

RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

ANALYST-TZB

GARY MURDOCK
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APPENDIX D

TECHTRAKS

Spectro-Metals

Glossary Description: Any of several techniques for detecting and quantifying trace metallic elements, in which the sample is energized to make the element(s) emit or absorb a quantifiable amount of light energy.

How is the test performed? Two methods prevail today: EMISSION – The sample is energized via electric arc. The elements emit discrete wavelengths of energy. Photomultiplier tubes (at least one for each element of interest) measure the amount of energy for each element. Energy measured is proportional to the concentration of each respective element. ABSORPTION – The element of interest absorbs light energy emitted from a tube whose cathode is made of that element. Absorption technique is confined to one element at a time.

Reporting Units: Parts-per-million (ppm) by weight. 1 ppm – 0.0001%

Repeatability: (approx.): 1-20 ppm (+/- 1ppm); 20-500 (+/- 5%); 500+ (+/- 8-10%)

Technical Overview: SP (Spectro-metals) is confined to the measurement of metallic particles <10 microns in size and is thus limited on detecting catastrophic failures. In some applications, it is a weaker alternative. There is insufficient energy available (in the standard process) to enable ionization of particles well below 10 microns (varying according to the type of spectrometer and the element one is attempting to detect, as well as the form the elements is in), which must occur if spectral energy is to be developed.

- Because SP is particularly effective for detecting extremely small particles (the smaller the better) it is one of the tests LEAST affected by the sampling technique. Sampling location however, should always be constant.

Interpretation: Spectrometals (SP) testing provides information on three distinct areas of interest: WEAR, CONTAMINATION, and ADDITIVES.

Wear Metals: Iron, Chrome, Molybdenum, Aluminum, Lead, Copper, Tin, Nickel, Silver, Antimony, Titanium.

Contaminant Metals: Silicon, Sodium, Potassium, Boron.

Additive Metals: Magnesium, Calcium, Barium, Phosphorus, Zinc.

Special Note: The listing above provides only the primary situation in which one may detect the metals. In reality, nearly every element can fit into all three categories and many fit into two routinely.

Spectro-Metals Sources

Aluminum (Al)

Wear sources: Piston; shell bearing; bushing; thrust; block; head; blower, additive (grease); cooler cores.

Environmental/contaminant sources: Crankcase paint; aluminum manufacturing, aluminum recycling; coal contaminant (trace levels).

Antimony (Sb)

Wear sources: Bearing alloy; babbitt alloy.

Additive: Tracer element.

Barium (Ba)

Sources: Lube additive.

Environmental/contaminant sources: Additive used in well service applications, contaminant carried through breather.

Boron (B)

Sources: Lube additive.

Environmental/contaminant sources: Coolant additive; mining.

Calcium (Ca)

Sources: Lube additive.

Environmental/contaminant sources: Water, mining product.

Chrome (Cr)

Wear Sources: Various plating, liner, ring, shaft; alloy (stainless steel), e.g., some shafts, gears.

Environmental/contaminant sources: Chromate coolant additive (mostly out of use now).

Copper (Cu)

Wear sources: Bushing; bearing; thrust; piston insert; gear; axial hydraulic piston assembly; cooler cores; rod packing (mostly out of use now).

Environmental/contaminant sources: Copper mines.

Additive: Occasionally used as an additive in automotive applications.

Lead (Pb)

Wear sources: Bearing overlay; bearing alloy; shaft; thrust plating; piston insert; wet clutch.

Environmental/contaminant sources: Mining; paint (mostly out of use now).

Additive: Gasoline additive (mostly out of use now).

Iron (Fe)

Wear Sources: Piston, ring, cylinder, gear; block; head; cam; shaft; roller bearing; shell bearing back; seal.

Environmental/contaminant sources: Rust, machining, mining.

Magnesium (Mg)

Sources: Lube additive; some turbine metallurgy.

Environmental/contaminant sources: Seawater.

Molybdenum (Mo)

Wear sources: Ring plating, alloy.

Additive: Oil additive, off the shelf supplement.

Nickel (Ni)

Wear sources: Steel alloy; ‘heavy’ fuel contaminant (usually with vanadium and sodium); stellite (cobalt-nickel) valve seat.

Phosphorus (P)

Sources: Lube additive; synthetic phosphate ester lube.

Wear: Brass/bronze alloy.

Environmental/contaminant sources: Phosphoric acid.

Potassium (K)

Environmental/contaminant sources: Coolant additive.

Silicon (Si)

Wear sources: Wet clutch; brake materials.

Environmental/contaminant sources: Abrasive (dirt); silicate coolant additive; silicone seal; glass manufacturing.

Additive: Defoamant additive; synthetic lube.

Silver (Ag)

Wear sources: EMD wrist pin bushing/turbo bearing; bearing plating or alloy (needle bearings).

Environmental/contaminant sources: Silver solder.

Sodium (Na)

Sources: Lube additive latent (harmless) from lube additive preparation.

Environmental/contaminant sources: Coolant additive; salt water.

Tin (Sn)

Wear sources: Bearing/bushing/piston plating or alloy.

Environmental/contaminant sources: Manufacturing processes, recycling processes.

Titanium (Ti)

Wear sources: Gas turbine bearings/hubs/blades.

Environmental/contaminant sources: Paint (White lead).

Zinc (Zn)

Sources: Lube additive.

Wear: Galvanized metals/plumbing; brass/bronze alloy

Limits: Some manufacturers have specifications for SP limits, but this is generally inadvisable, as there are too many variables that affect results, among them:

- Dispersion characteristics of the additive package which helps hold metals in suspension
- Filtration scheme and equipment
- Lube consumption which dilutes values
- Equipment application
- Manufacturer and model of component
- Fluid and unit service time

Wear trends take into account the unique characteristics of equipment and are, therefore, more reliable than limits.

Suggested Application: All systems benefit from this test. It is very inexpensive for the amount of potential information it can provide. While less effective in rotary systems, it is still very useful.

Viscosity

Glossary Description: A fluid's resistance to flow with respect to temperature.

How is the test performed? The fluid is placed in a 'viscometer', (a calibrated capillary tube for precise flow measurement between two pre-marked points on the tube) and pre-heated to a given temperature in a 'viscosity bath' (which is usually oil-filled). After the oil reaches the temperature at which the viscosity is desired, gravity-influenced flow of the oil is initiated in the viscometer and timed between two calibrated points. This time becomes the determinant for the result.

Reporting Units: "Centistoke" (cs., cSt) is presently the customary unit.

Accuracy/Sensitivity: +/- 3% of value is expected in most used lubes, slightly better for new lubes.

Technical Overview: Shearing of a lube occurs when its molecules are split into yet smaller molecules. This can happen from two basic processes: heat & pressure from the system (this can affect even the lubes base stock, though more aptly applies to any viscosity-index improvers which may have been present); mechanical shearing, such as ring scraping against a cylinder wall, trapping lube molecules and cutting them. Viscosity Index is a measure of a lubes resistance to thinning as temperature rises, an important property, particularly in cold climates: one wants a LOW viscosity for pump-ability, but then wants the lube to remain thick enough to provide film strength at operating temperature. Polymer-based "VI improvers" help accomplish this in motor oils, in particular. VI is of little use in used motor lube analysis, too many variables preclude a valid assessment.

What causes viscosity to change?

Upward

- Lube oxidation
- Foaming/Pump Cavitation
- Emulsion with water
- Wrong fill or make-up lube (higher viscosity than recommended)
- Soot or Solids contamination

Downward

- Fuel or solvent contamination
- Molecular shearing (see above)
- Non-emulsified water contamination
- Wrong fill or make-up lube (lower viscosity than recommended)
- Refrigerant (air conditioning systems)

Suggested application: Viscosity is recommended for any application.

Fuel Soot

Glossary Description: Combustion solids from reciprocating engines, however, the primary application is diesel engines.

How is the test performed? With IR one draws inferences from sample opacity (light dispersion) and certain absorbencies. A standard reference curve is then developed and stored in the infrared spectrometer's on-board computer. This particular approach has been correlated against a more rigorous technique, thermo-gravimetric analysis, with near-linearity to 3%, useful to 5%.

Reporting Units: Percent of SOOT contamination by volume.

Accuracy/Range: 0.2% or +/- 10% of value, whichever is greater. Practical range: 0.1 to 5.0%.

Technical Overview: This test was developed primarily with Diesel engines in mind, as their combustion nature produces the most obvious soot. More recently it has been disclosed that "fuel soot", although it causes no known direct-wear problems in moderate amounts, DOES evidently "tie up" the anti-wear additive (any of several possible forms of zinc di-thiophosphate) to some extent, rendering the additive less effective. Excessive solids may possibly impair anti-wear benefits and, indirectly, perhaps lead to additional wear above "normal" for given unit. Do not confuse SOOT discussed here with (see) Particle Count or DR Ferrography. The latter are entirely different investigative aspects.

Interpretation: Significance of soot/solids will vary according to unit type, model and application. Diesel Engines (0.1 to 5.0%): Combustion solids or "fuel soot" (mostly carbon from incomplete fuel burn but can also contain oxidized fuel and/or lube, the latter more lacquer-like in nature).

If excessive, possible causes are:

Wear – oriented

Turbocharger or blower seal leakage
Blow-by (excessive crankcase pressure)
As applicable; Worn pistons, rings, cylinders
worn accessory drive air compressor
Worn valves/guides or other area of valve train

Operations – oriented

Lube change interval too long
Over fueling or excessive idling
Incorrect rack setting
Restricted air intake
Excessive exhaust backpressure
Leaking/worn injector nozzle

Gasoline Engines (0.1 to 1.15): Combustion blow-by, if excessive, possible causes: Overextended drain, timing/tune-up needed, excessive temperatures.

4-Cycle Gas Engines (0.1 to 2.0): Combustion blow-by, oxidized/nitrated fuel/lube, if excessive, possible causes: Fueling/timing problems, overextended drain, low operating temperatures.

Suggested Application: All diesel engines, some gasoline engines and gas-fired engines.

Infrared Analysis (IR)

Glossary Description: A form of absorption spectroscopy (IR) confined to the infrared spectral wavelength region, which primarily addresses identification and quantification of organic functional groups.

How is the test performed? A thin layer (approx. 0.1 mm) of lube is spread on a zinc selenide crystal. Infrared radiation is directed at the sample (though the crystal's bottom side) and a detector measures the amount of energy absorbed on a per-wavelength basis. Specific classes of compounds absorb specific infrared wavelengths, allowing detection and quantification. A computer subtracts the reference from the sample, providing results as a difference, with the exception of the hydrocarbon value, which is reported without a reference subtraction.

Reporting Units: Absorption units (AU) per centimeter (cm) in the form, x.xxxx (or some variation of multiple thereof; we use xxxx).

Expected Repeatability: +/- 3 AU or 5%, whichever is greater.

Technical Overview: IR deals mainly with the chemistry of a lubricant's base stock and additive packages (if any). For lube analysis purposes it might be considered the chemistry of Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus and Sulfur, even more specifically, the configurations and combinations in which these elements are linked (referred to as "functional groups"), but IR is certainly not limited to these elements. "FTIR" (Fourier Transforms IR, after the French mathematician), is the current technical standard for IR. Fourier Transforms allow the generation of complex curves from digitally represented data. An on-board computer allows data acquisition/storage, as well as provides the number crunching power to achieve the transforms rapidly, thus, Fast FTIR (FFTIR), a very powerful technique.

Interpretation: There are two basic types of results available: Individual absorption readings at specific wavelengths (most common) to investigate specific characteristics; Complete wavelength scanning (or curving) for product matching and investigation of unknowns.

Used lube analysis often utilizes specific wavelengths for repetitive logging of data on an individual sump. By so doing one may be able to identify and develop trends as with other test procedures.

<u>Wavelength</u>	<u>Functional Group</u>	<u>Range</u>
2.9 microns	Water	0 – 5
3.5 microns	Hydrocarbon (identifies if mineral oil or synthetic)	500 – 1000
5.8 microns	Oxidation	0 – 24
6.1 microns	Nitration	0 – 24
9.6 microns	Glycol	0 – 50

The above ranges are for orientation purposes only. As with most used lube testing it is often trends, not absolute number, which determine when to conclude, for instance, that the lube has "oxidized" to a significant extent. Baseline data from new lube references are very important if correct inferences are to be made. The client's onsite supply should be the baseline source, since batches of lube may significantly vary in IR absorption properties, thus semi-annual lube storage sampling is advised in order to remain current.

Suggested Application: IR is amenable to any lube system, offering its fullest possibilities with reciprocating engines and compressors. Hydraulic systems and gearboxes are also applicable.

Total Base Number (TBN)

Glossary Description: A neutralization number intended for measuring all basic (alkaline) materials in the lube, e.g. acid-neutralizing components in the lubes additive package.

How the test is performed? The sample is diluted with solvent and acid (hydrochloric {HCL} or perchloric {H3PO4}) is added in controlled increments from a buret (a calibrated tube with a stopcock valve at the bottom to allow gravity feed) until the sample is neutralized. This process is called a titration. The acid is the titrant. Neutralization is determined with a volt or pH meter, and the neutralization point usually occurs around pH 4. The amount of acid consumed is recorded and the TBN calculated from that value.

Reporting Units: Milligrams (mg) of potassium hydroxide (KOH)*/milliliter (ml) of lube.
Repeatability: +/- 10%. Range: 0.01 – 80 (encompassing virtually all systems).

Technical Overview: *It appears incongruous to express TBN in terms of KOH, in as much as HCL is the titrant, but this convention renders TBN and TAN (total acid number) ‘compatible’ in term of relative magnitude (neutralization numbers utilize the atomic formula weight of the titrant in the calculation – KOH’s formula weight is more than 1.5 time HCL’s). The only oddity of this notion is that TBN and TAN don’t necessarily relate to one another, nor is one the opposite of the other (it is possible and usual for a motor lube to have a TBN and TAN simultaneously), so there is no real need to develop a common denominator. Note: ASTM D664 TBN method has given way (and will not be retained by ASTM as a method) to D2896 (“perchloric acid method”) as the recommended method for new lubes, as well as general practice. D664 however, still has practical use in traditional used lube analysis and will probably remain to some degree for at least awhile. Note: TAN, in conjunction with TBN, is recommended for extended drain interval evaluations.

– Recently ASTM D4739 has been developed as a probable alternative to D664.

Interpretation: TBN is a measure of the lube’s alkaline reserve and mostly applies to motor lubes. If a lube contains no alkaline additives, there is little use to determining a TBN, as there will likely be none. TBN is attacked by combustion acids, e.g., Sulfuric Acid, decreasing as it consumes. There are varying schools of thoughts as to when a TBN is sufficiently low enough to suggest a drain.

Crude “Rule of Thumb”: If TBN decreases to 2.0 or decreases more than 50% from starting point, a drain should be contemplated. One needs to be careful here – although a used lubricant may exhibit a TBN of, say, 2.0, there may be a need for a higher TBN level at the point of combustion blow-by attack (the ring belt area). Although the entire crankcase has TBN 2.0 in it, only a small portion of it can be at the “battle point”, particularly when engine shutdown occurs and the cylinder areas reach dew point for water condensation. A safety margin should be considered whenever sulfur is a potential problem.

Some manufacturers may impose a ratio of TBN to sulfur %; levels of 10-20 might be specified. Gasoline does not directly pose a sulfur problem to an engine. Instead, gasoline engines, owing to their fuel type and combustion mechanism, tend to form complex peroxy acids, which ultimately attack the TBN. Marine cylinder lube types may have TBN’s as high as the 70’s, as these lubes must combat sulfur levels as lofty as several percent, dependent on the fuel type and point of origin. The rule of 20 time sulfur levels for TBN seems to hold true for this application.

Suggested Application: Reciprocating engines, natural gas engines and compressors using alkaline lube, alkaline environment situations where the lube does not contain alkaline additives, but can be contaminated with alkaline materials.

Total Acid Number (TAN)

Glossary Description: A neutralization number intended for measuring all acidic and acid-acting materials in the lube, including strong and weak acids.

How is the test performed? The sample is diluted with solvent and base (alkaline), in the form of potassium hydroxide (KOH), which is added in controlled increments from a buret (a calibrated tube with a stopcock valve at the bottom to allow gravity feed) until the sample is neutralized. This process is called a titration. The KOH is the titrant. Neutralization is determined with a volt or pH meter, and the neutralization point usually occurs around pH 11. The AN is calculated from the amount of KOH consumed.

Reporting Units: Milligrams (mg) of potassium hydroxide/milliliter (ml) of lube.

Repeatability: +/- 10% Range: 0.01 – 20 (practical)

Technical Overview: Many standard lube additives yield a non-harmful TAN even as new, thus it is important to establish baseline values. Phosphorus/Zinc compounds may contribute as much as 2.0 TAN dependent upon concentrations. Magnesium, Calcium, and Barium (even though they are alkaline contributors), can still yield an TAN value of as much as 2-3, again dependent upon concentration, so a ‘fully compounded’ lube might easily have a starting acid number of 2-5. This is a difficult concept to find comfort with, but it stems from the tendency to regard all acids as corrosive, rather than acids in the sense of their electrochemical behavior, i.e., there are degrees of acid behavior. Such degrees are expressed as pH, which represents acid strength (lower = greater strength), but not necessarily the quality. PH, therefore, does not relate to AN in any sense.

Interpretation: AN is comprised of both strong and weak acids. Strong acids tend to be corrosive, and are accordingly much more necessary to control. Examples of strong acids are:

- Hydrochloric Acid (HCL) breakdown of freon in refrigeration compressors; certain work environments.
- Hydrofluoric Acid (HF) breakdown of freon.
- Sulfuric Acid (H₂SO₄) Diesel combustion by-product from sulfur in fuel; certain work environments.
- Nitric Acid (HNO₃) certain work environments (e.g., a phosphate mine).

All of the above will etch or corrode various metals in varying degrees. A low pH (<4.5) probably indicates the presence of one or more of the above acid types in at least the beginning stages of concern, particularly if water is present, since the acid can then achieve its fullest chemical potential.

Weak acids do not usually cause corrosion problems, but certain leaded bearings and coatings can be attacked by weak acids. Often times the development of weak acids may indicate lube oxidation and, as such, represents an effect, not a cause. Once this occurs to excess, however, it can be self-sustaining, thus a lube might need to be drained (or “sweetened” {a partial drain}, if the sump capacity is too large to drain economically).

Crude “Rule of Thumb”: Increases of 2.0 or 50% (whichever is greater) against baseline (new lube reference) = drain or sweeten (drain partially and top with fresh oil).

Suggested Application: Plant equipment; engines using high sulfur fuel, most non-engines, extended drain studies for engines.

Particle Count (PC)

Glossary Description: Any of several techniques to categorize particles in a fluid with respect to number and size range.

How the test is performed? A volume of sample is flowed through a small orifice that has a light source on one side, and an optical sensor on the other. Particles interrupt light impinging on the sensor, causing a pulse or “count” to be generated. The duration of the pulse will vary with and relate to size, enabling a categorization or sizing to be determined. A technician (or computer) reads as many as six channels, each set to record a specific size range. The set of results is the Particle Count (PC).

Reporting Units: Micron range and count in particles/ml is standard. Two common ranges: ISO (International Standards Organization): 5-10-15-25-50 microns; OSU (Oklahoma State Univ.): >10>20>30>40 microns. “ISO ratings” (in the form of xx/yy) are derived from counts obtained at 5 microns and 15 microns. Current ISO reporting may include a count at 2 microns, resulting in an ISO no.: xx/yy/zz.

- Water and high opacity preclude an accurate particle count, as the sensor is ‘fooled’ into counting water droplets as particles. If the sample is opaque it is necessary to dilute the sample, which may reduce the value of the information. Our usual practice when this situation arises is to perform a Direct Reading Ferrograph, which is not sensitive to water, or opacity (see TechTraks on DR Ferrography).

Sampling technique is more critical for this test than any other, as it is relatively easy to begin with contaminated containers or to contaminate the container as one samples. Severe increases in PC without support from other tests might, therefore, suggest verification re-sampling.

Interpretation: Particles come from two sources: Wear and Contamination. It is not always easy to determine which of the two sources applies (seals produce both ‘wear and contamination’ particles), since PC doesn’t identify the nature (shape or composition) of the particles. Nevertheless any particle can cause wear, leading to yet more particles, so that it is essential to control them. For this reason limits are emphasized equally with trends in the evaluation process. The most basic control of particle formation is to service filter systems; this might consist of a filter change, or may involve the use of off-line filtration when levels are deemed too high to control with a simple filter change.

- If abnormal PC levels persist despite standard control methods, additional testing (such as Analytical Ferrography or Micropatch) should be undertaken, as excessive wear, rather than contamination may be occurring.

Suggested Application: PC is best applied to systems with filtration control. Hydraulics are most amenable. Other systems: compressors, 2 cycle gas engines, auto-powershift transmissions, and other filtered rotary systems.

Direct Reading Ferrography (DR)

Glossary Description: Literally translated as “iron writing”; it is a technique utilizing a precision magnetic gradient to systematically strip iron-laden and other susceptible particles from a lube for study.

How is the test performed? A small amount of sample is diluted with solvent and flowed through a small capillary tube, which runs through a magnetic field. Iron-based particles are systematically (largest to smallest) “pinned” by the magnetic field as the sample flows through the capillary tube. Two optical sensors are respectively set at the entrance and slightly downstream of the capillary tube to measure the density of the (iron) particles collected at each of the two points.

Results Range: (L or S): 0.0 – 198 (higher involves dilution).

Repeatability: +/- 5% or 0.3 reporting unit, whichever is greater, thus : 150 (142.5 – 157.5) or 0.8 (0.5 – 1.1).

Technical Overview: DR Ferrography does not yield information about the particle morphology (shape), nor does it do other than size particles into two broad categories. It does, however, possess the advantage of not being highly affected by sample opacity or water contamination and is, as such, a fairly repeatable test, given proper sampling procedure. It can be applied, therefore, in circumstances where other methods are rendered ineffective. It is, for example, a quite reasonable alternative to particle counting.

Result/Interpretation: Two scalar reading, “L” and “S”, are obtained:

“L” or Large particles (approx. >5 microns)	L + S = WPC (Wear particle concentration)
“S” or Small particles (approx. <5 microns)	L (L – S) = WSI (Wear severity index)

Various systems show different “typical” levels. It is very important to watch trend development as opposed to numerical “limits”.

It is unwise to inspect a unit solely on the basis of “abnormal” DR Ferrograph readings without:

1. Results from additional tests, which support such a decision.
2. Resubmitting a sample for verification.

Alternatively, consider having an Analytical Ferrogram developed for microscopic study. Levels alone are not always the determining factor: a reading of 75.3 (L) / 23.00 (S) {a ratio of 3.3} might be considerably more of a concern than, say, one of 140 / 130 {a ratio of 1.1}. A change in ratio may be very meaningful in certain instances.

Suggested Application: In the broadest sense, almost any system is amenable to DR Ferrography, but the most useful application is with non-filtered rotary systems (most differentials, manual transmissions, speed increasers/reducers, isolated bearings/shafts); the most amenable filtered systems: gas turbines, rotary screw compressors, slow/medium speed reciprocating engines and compressors (e.g., natural gas and marine installations) diesel, and gasoline engines.

Analytical Ferrography (AF)

Glossary Description: Literally translated as “iron writing”; it is a technique utilizing a precision magnetic gradient to systematically strip iron-laden and other susceptible particles from a lube for study.

How is the test performed? A small amount of sample is diluted with solvent and flowed across the length of an inclined microscope slide, the slide is flanked by specially designed permanent magnets, causing magnetic particles to be systematically stripped and deposited.

Technical Overview: Analytical ferrography addresses particles, which are larger than those detectable by rapid-process atomic emission or absorption spectrometers (which are limited to particles <10 microns). Further, the process yields morphology (shape) of particles, which in turn frequently reveals the cause of a problem. It is one of the most powerful and revealing tools used in lube analysis consulting. It is not, however, an end-all. At the time of this writing there is no single test to supplant all others.

Result/Interpretation: A ferrogram is an ordered precipitation (from large to small) of magnetic particles on a slide, and a semi-random precipitation of non-magnetic particles, as influenced by gravity. The slide is viewed under a ferroscope (a special microscope for illuminating with two differently colored light sources). An experienced technician “grades” various types of particles (see below). A pertinent photograph is usually taken as well, and a brief narrative may also accompany the photograph. The unit history report will usually have a coded interpretation of the information.

Ratings:

0 = None detected 1 = Few 2 = Moderate 3 = Significant 4 = Very dense

In addition to numerical ratings there will be a letter classification to identify particle type:

- (A) *Abrasives:* Sand, “dirt”, usually silicon-based particles that appear translucent.
- (C) *Cutting wear:* Curved or spiral metals signifying, e.g., a lathe or lapping-type effect from an abrasive lodged in a relatively soft bearing while cutting into the shaft.
- (D) *Dark metallo-oxide:* Indicative of severe heat from metal-to-metal contact, e.g., lube film break down.
- (E) *Fatigue-oriented metal:* Metals with diameter >15 microns in size, indicating component distress and potential catastrophic failure.
- (F) *Fiber:* Individual strands, often from filter media, occasionally from shop rags and other debris.
- (L) *Laminar:* Metals having a “peeled” look (thin, long), often from roller bearings.
- (N) *Non-Ferrous metal:* Any metal that is not primarily iron, e.g., brass bronze, aluminum, babbitt.
- (O) *Corrosive:* Extremely small (<1 micron) particles found in the “tail” (last flow point) of the ferrogram, indicative of hostile environment or over-extension of lube drain.
- (P) *Friction Polymer:* Appears as a nearly clear lacquer-like particle, often with embedded metals. Tends to indicate lube distress from “hot Spots” in the system or misapplication of lubricant, e.g., too low a viscosity, resulting in insufficient film strength.
- (R) *Rubbing wear:* Small particles (<15 microns technically, but usually much smaller) which are expected or normal in many systems.
- (S) *Sphere:* Nearly perfectly round and mostly small particles (<3 microns) often from fissures in roller bearing elements. A significant increase may foretell spalling of the bearing. May also be weld/grind material.
- (X) *Red oxide:* Usually oxides of iron (e.g., rust); indication of latent water contamination.

Suggested Application: To support inspection decision. AF is a requirement for most predictive and proactive maintenance programs.

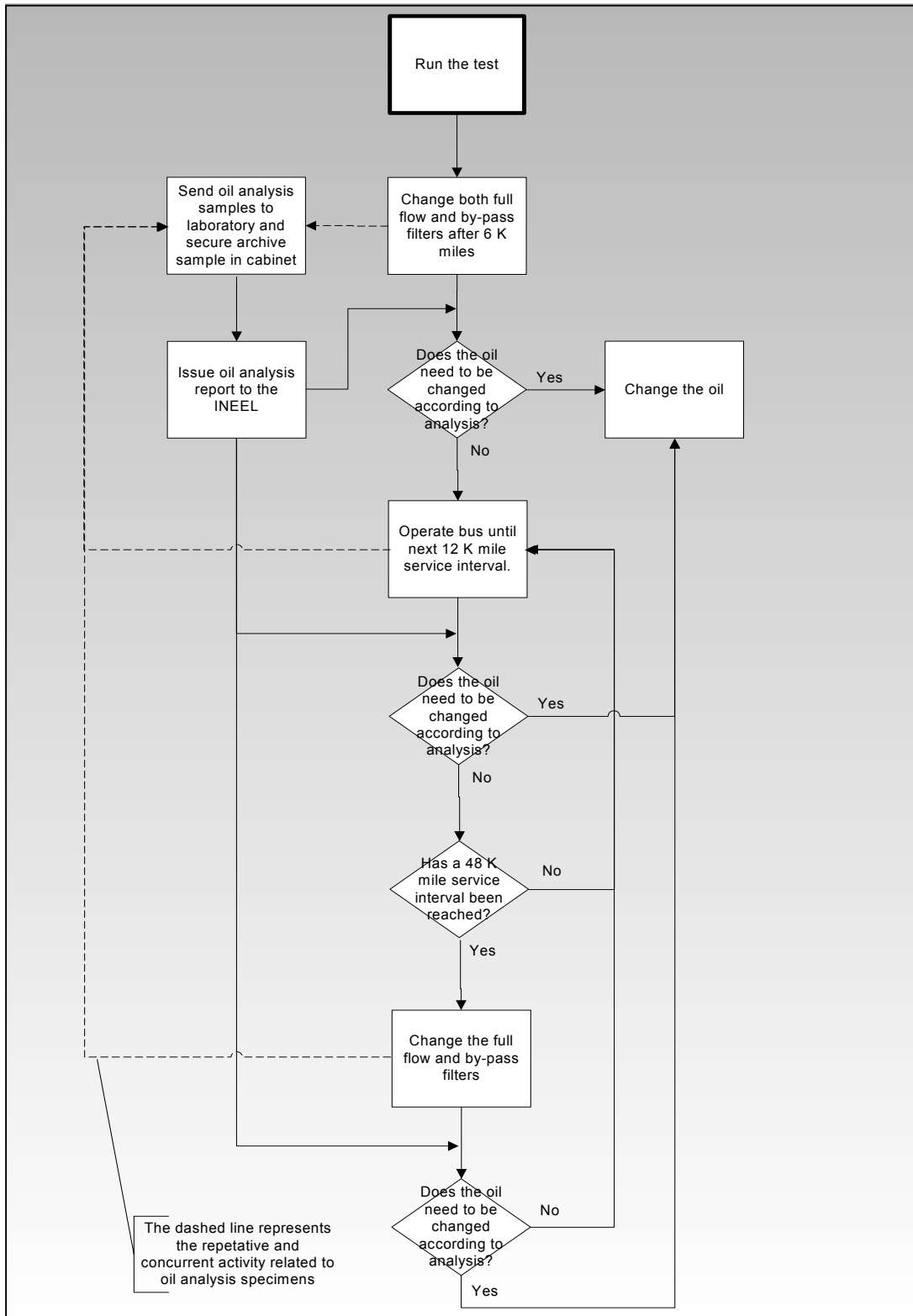
APPENDIX E
DAILY OIL USAGE LOG

Daily Oil Usage Log
(only log days when oil was added not days checked)

Bus Number:		NOTE: Use only Shell Rotella, 15w-40 oil			
Date	Quarts	Date	Quarts	Date	Quarts

APPENDIX F

CHANGING THE FILTERS



APPENDIX G

EXTENDED OIL DRAIN SCHEDULE



NOTE: DO NOT CHANGE OIL.
CONTINUE USING OIL IF LAB REPORT
SPECIFIED OIL IS UP TO SPECS FOR
CONTINUING USE.

EXTENDED OIL DRAIN SCHEDULE

Oil does not wear out; it gets dirty!

Keep it clean with the puraDYN® By-Pass Oil Filtration System

HRS	Mileage	One Half Interval #	OEM Interval	OEM Interval	OEM Interval	OEM Interval	OEM Interval	OEM Interval	OEM Interval	OEM Interval	OEM Interval
Oil Analysis	Change	YES*	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*
Sample	Change	Change	Change	Change	Change	Change	Change	Change	Change	Change	Change
puraDYN Oil Filtration Filter	Change	Change	Change	Change	Change	Change	Change	Change	Change	Change	Change
Full Flow Filter	Change	Change	Suggest Change Every 12 Months or 60,000 Miles, or 1,500 hours or whichever comes first; 50,000 miles for Model TF8SP and recreational vehicles.								
Oil Change	Change	Change	No Oil Change Required Unless Specified In Oil Analysis Report								

When puraDYN Oil Filtration System is installed/retrofitted as an aftermarket item, change oil and full flow filter at time of installation. Then at one-half manufacturer recommended drain interval, again change puraDYN Oil Filtration filter and full-flow filter, and do oil analysis. Thereafter, change puraDYN Oil Filtration filter and perform oil analysis at normal drain interval.

*Oil Analysis: oil sample should be taken with engine running

APPENDIX H

DECISION ANALYSIS AND DISPOSITION CHART

