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

# *Oil Bypass Filter Technology Evaluation Fourth Quarterly Report July-September 2003*

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*November 2003*

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

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# Fourth Quarterly Report
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### *Disclaimer*

# ABSTRACT

This fourth Oil Bypass Filter Technology Evaluation report details the ongoing fleet evaluation of an oil bypass filter technology by the Idaho National Engineering and Environmental Laboratory (INEEL) for the U.S. Department of Energy's FreedomCAR & Vehicle Technologies Program. Eight four-cycle diesel-engine buses used to transport INEEL employees on various routes have been equipped with oil bypass filter systems from the puraDYN Corporation. The bypass filters are reported to have engine oil filtering capability of <1 micron and a built-in additive package to facilitate extended oil-drain intervals. To date, the eight buses have accumulated 259,398 test miles. This represents an avoidance of 21 oil changes, which equates to 740 quarts (185 gallons) of oil not used or disposed of. To validate the extended oil-drain intervals, an oil-analysis regime evaluates the fitness of the oil for continued service by monitoring the presence of necessary additives, undesirable contaminants, and engine-wear metals. For bus 73450, higher values of iron have been reported, but the wear rate ratio (parts per million of iron per thousand miles driven) has remained consistent. In anticipation of also evaluating oil bypass systems on six Chevrolet Tahoe sport utility vehicles, the oil is being sampled on each of the Tahoes to develop a characterization history or baseline for each engine.

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# Oil Bypass Filter Technology Evaluation
# Fourth Quarterly Report

## INTRODUCTION AND BACKGROUND

This quarterly report of the oil bypass filter technology performance evaluation covers the evaluation period July through September 2003.[1] Eight puraDYN PFT-40 (40-quart capacity) oil bypass filter systems (Figure 1) are being tested on eight Idaho National Engineering and Environmental Laboratory (INEEL) buses. The eight buses are equipped with the following types of four-cycle diesel engines:

- Three buses, Series-50 Detroit Diesel engines
- Four buses, Series-60 Detroit Diesel engines
- One bus, Model 310 Caterpillar engine.

The first quarterly report extensively details the project background, safety considerations, preliminary economic analysis, and the test plan (Evaluation Test Plan EVH-TP-146 is available as Attachment 1 in the *Oil Bypass Filter Technology Performance Evaluation – First Quarterly Report,* INEEL/EXT-03-00129). The second quarterly report details the revised filter change schedule for the test and shows preliminary trends of the oil analysis report for one of the buses.[2] The third quarterly report details the bus mileage and performance status, preliminary trends in oil analysis, revised economic analysis, some ancillary data, and the status of the light-duty vehicle filter evaluation[3].

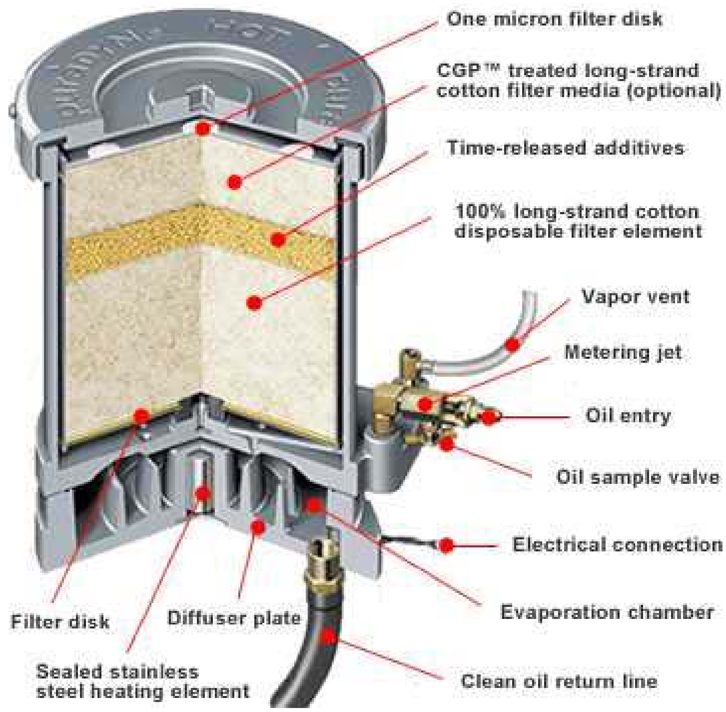


Figure 1. Cutaway drawing of a puraDYN oil-bypass filter.

Items reported in this Fourth Quarterly Report include:

- Bus mileage and performance status
- Oil analysis reports
- Used engine oil disposal costs
- Unscheduled oil change
- Status of the light-duty vehicle filter evaluation.

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[1] The DOE FreedomCAR and Vehicle Technologies Program funds these activities.
[2] INEEL/EXT-03-00620.
[3] INEEL/EXT-03-00974.

## BUS MILEAGE AND PERFORMANCE STATUS

During this quarter (July–September), the eight buses traveled approximately 74,410 miles (Figure 2). Typically, the buses travel established routes, carrying INEEL workers during their morning and evening trips to and from the INEEL test site (100+ miles per round-trip). When possible, the fleet operations manager assigns the eight buses to shuttle runs during off-peak hours to add evaluation mileage. Table 1 details the mileage status of the eight test buses. Figure 3 shows the total evaluation miles per bus, by evaluation quarter.

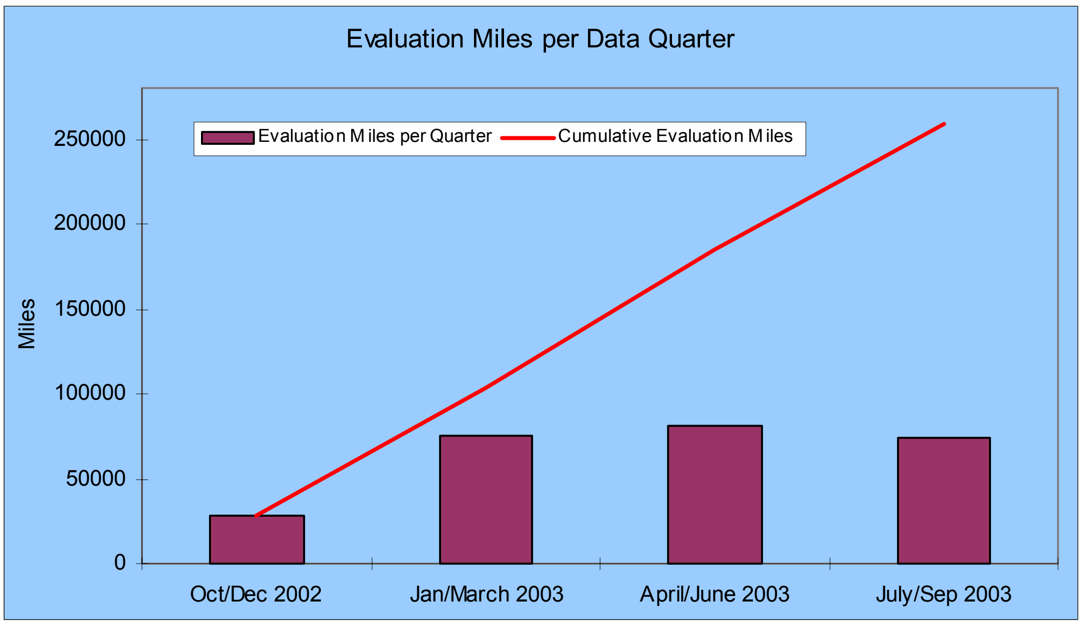


Figure 2. Quarterly and cumulative evaluation miles per evaluation quarter.

Table 1. Test buses and test mileage on the oil at 9/30/03.

| Bus Number | Starting Date | Bus Mileage at Start Date | Current Bus Mileage (09/30/03) | Total Oil Evaluation Test Miles |
|---|---|---|---|---|
| 73425 | 12/18/2002 | 41,969 | 60,829 | 18,860 |
| 73432 | 2/11/2003 | 47,612 | 77,141 | 29,529 |
| 73433 | 12/4/2002 | 198,582 | 230,011 | 31,429 |
| 73446 | 10/23/2002 | 117,668 | 153,390 | 35,722 |
| 73447 | 11/14/2002 | 98,069 | 122,811 | 24,742 |
| 73448 | 11/14/2002 | 150,600 | 177,062 | 26,462[1] |
| 73449 | 11/13/2002 | 110,572 | 135,701 | 25,129 |
| 73450 | 11/20/2002 | 113,502 | 181,027 | 67,525 |
| | | Total Test Miles to Date (09/30/03) | | 259,398 |

[1] The oil on bus 73448 was inadvertently changed on 9/16/03. This total includes both oil tests on bus 73448.

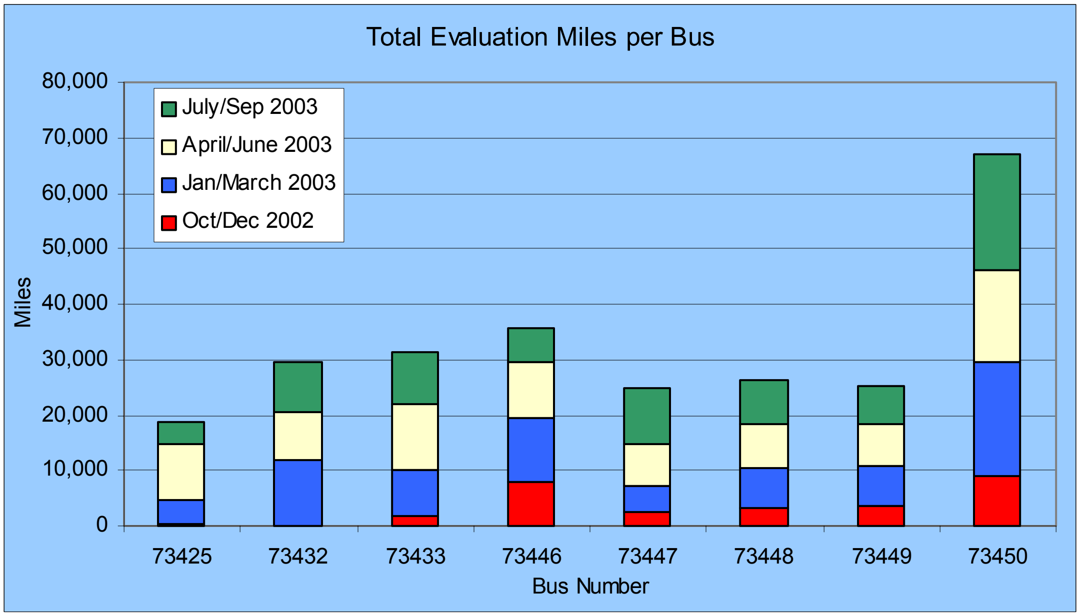


Figure 3. Total evaluation miles per bus by testing quarter.

## OIL ANALYSIS TESTING AND REPORTING

For this oil bypass filter technology performance evaluation, all bus oils were both sampled and analyzed at the start of the test, at 6,000 miles, at 12,000 miles, and at each 12,000-mile interval thereafter. Each sample is split three ways; two portions are sent to two independent laboratories for analysis, and the third portion is archived at the INEEL (discussed in the *First Quarterly Report*). The data from both laboratory analysis reports are compiled to document and track the oil quality and the engine metal-wear pattern profiles. To date, a total of 54 (29 with one laboratory and 25 with the other) oil analysis records make up the profile database. The sampling interval coincides with the servicing of buses, and since the oil is not changed, only the filters are replaced during the servicing event. Additional or informational oil analysis samples are sometimes taken at the discretion of the shop foreman or test engineer if an anomaly or abnormality appears in an oil analysis report.

The oil analysis reports typically have five basic aspects:

1. Engine wear metal analysis, such as iron and copper
2. Chemical tests for pollutants, such as water, fuel, soot, and coolant
3. Oil condition analysis, such as viscosity and TBN (total base number) values
4. Previous test results
5. Laboratory statement on the condition or status of the engine or oil (normal, abnormal, or critical).

When an engine has a high or higher levels of engine wear metal, it suggests that a bearing or engine part is wearing, and appropriate action should be taken before a catastrophic and costly engine failure occurs. However, the oil quality values generated in the chemical and oil condition tests (TBN, viscosity, soot content, water level, and glycol level) reflect fitness for service and are the metrics for determining oil quality during this test. (An oil analysis report is shown in Appendix C, of Attachment 1 of the test plan presented in the *First Quarterly Report*). The test results from the oil analysis reports for this bypass system evaluation reveal several factors that must be considered when evaluating the oil, including:

- Engines have their own wear metal signature

- Oil analysis laboratories have their own values or limits on oil quality
- Oil analysis laboratory results databases are based on oil that is discarded at each servicing interval
- Oil analysis reports from different laboratories are sometimes contradictory
- Judgment to change the engine oil has a qualitative flavor instead of a purely quantitative one
- A database of oil analysis reports germane to extended oil drain interval tests has not been identified.

## Trends

Bus 73450, with a Caterpillar 310, six-cylinder, four-cycle engine, has the most mileage of all the test buses and, consequently, has had the most sets (seven) of oil analyses performed on its test oil. Typically, the oil analysis samples are taken when the bus oil filters are serviced; however, this bus has had additional samples taken to monitor perceived high iron levels. The bus shows high or higher levels of iron over the last several reports:

- The last five CTC Laboratory report values for iron are between 91 and 212 parts per million (ppm).
- The last four ANA Laboratory report values for iron are between 86 and 252 ppm.

Each engine has its own unique wear metal characteristic, but a rule of thumb is that 30 ppm is a typical established wear value.

Bus 73447, with a Detroit Diesel series 60, six-cylinder, four-cycle engine, is beginning a possible trend with significantly higher levels of both copper and potassium on the last two analysis reports. Copper is a contaminate from bearings or radiators (coolant radiator, oil cooler, or heater cores). Potassium is a contaminate metal usually from a coolant leak. The next report may affirm any trends.

It is too early in the evaluation process to pronounce any other definitive conclusions, but it is worth discussing some of the initial testing results. Testing results to date support the belief that each engine is unique, and each engine has its own wear pattern.

## Parts per Million Iron Increase

The high levels of iron in bus 73450 indicates to the fleet maintenance personnel that an iron engine part is believed to be wearing more then normal, and it serves as a warning of a potential catastrophic engine failure. The INEEL shop foreman scheduled intermediate oil analysis samples to monitor this engine's condition. It is disconcerting to the maintenance shop personnel to have an oil analysis report come back with an "Abnormal" evaluation for oil, but this abnormal evaluation is based on the iron content. High iron ppm is not deleterious to the engine oil, and the high ppm of iron in bus 73450 does not warrant changing the oil. To better understand this, one must consider the wear rate ratio.

## Wear Rate Analysis

Typically, when an oil analysis sample is taken, it is taken on oil discarded at a scheduled servicing interval, and when the analysis report is received, it is on oil that has been discarded. This method of obtaining oil analysis reports is mainly used as a method for identifying wear metals and oil contamination from engine operation, and from the coolant and air filtration systems. Using extended oil change intervals goes against the paradigm of regular oil changes; a negative trend of iron values can, therefore, be somewhat misleading when viewed conventionally.

For the oil bypass filter technology evaluation, the oil is evaluated when the filters are changed, and it continues to be used for an extended time, until the oil analyses warrant changing the engine oil. With extended drain intervals, metals can continue to accumulate at a "normal" pace, while the analysis results suggest dangerously high levels of accumulated contaminants. One technique to evaluate accumulated metal wear levels is to look at the wear rate ratio.

Wear rate ratio is determined by dividing the total ppm of metal in the oil by each 1,000 miles traveled. If the wear rate remains relatively constant over time, the high metal content is not considered to be deleterious. If the wear rate were to radically increase (double or triple) with each oil analysis, then action should be taken, i.e., tear down the engine to remove the failing part. Table 2 shows bus 73450's wear rate ratio calculated from the last seven-oil analysis reports from CTC Analytical Services. With the exception of the 1/8/03 and 6/16/03 test results, the wear rate is relatively constant. Therefore, the higher iron level (measured in ppm) is not considered to be deleterious. The 1/8/03 low iron results are likely due to the newness of the oil and the few test miles. The 6/16/03 results are likely the result of the bus being driven 4,800 miles beyond the normal sampling period and bypass filter insert replacement at 12,000 miles.

Table 2. Bus 73450 wear rate results from CTC Analytical Services.

| Sample Date | Total Bus Mileage | Miles Between Tests | Accumulated Oil Test Miles | Iron ppm | Iron Wear Rate Ratio (ppm/K miles) |
|---|---|---|---|---|---|
| Start 11/20/02 | 113,502 | | | | |
| 1/8/03 | 124,056 | 10,554 | 10,554 | 20 | 1.90 |
| 1/21/03 | 127,052 | 2,996 | 13,550 | 50 | 3.69 |
| 3/17/03 | 139,704 | 12,652 | 26,202 | 91 | 3.47 |
| 6/16/03 | 156,539 | 16,835 | 43,037 | 206 | 4.79 |
| 7/2/03 | 160,410 | 3,871 | 46,908 | 162 | 3.45 |
| 7/23/03 | 165,376 | 4,966 | 51,874 | 183 | 3.53 |
| 8/25/03 | 172,309 | 6,933 | 58,807 | 212 | 3.61 |

ppm = parts per million.
Wear rate ratio = ratio of ppm to each 1,000 miles traveled.

## Oxidation and Nitration Analysis

With regular oil change intervals, harmful oxidation and nitration levels in the oil may never be evident because the motor oil is periodically discarded. However, with extended oil-drain intervals, it is possible for oxidation and nitration of the oil to occur due to the effects of aging, heating and combustion efficiencies. Therefore, oxidation and nitration analysis tests have been added to the original suite of oil analysis tests previously used to measure the oil quality. These tests will be a secondary measure of oil quality heretofore not available with the previous suite of oil analysis tests.

Fourier Transform Infrared Spectroscopy (FTIR) is used to determine the oxidation and nitration values of oil. ASTM E 168-99 describes the general techniques of infrared quantitative analysis. FTIR identifies types of chemical bonds in an oil molecule by producing a plot of its infrared absorption spectrum. The spectrum for CARBONYL (a suite of oxidation degradation products) has a spectrum value of 1730/cm. The spectrum for organic nitrates (a suite of nitration degradation products) has a wavelength value of 1630/cm. The peak values at these points on the spectrum plot measure the amount of light absorbed and show the relative oxidation and nitration of the oil in Absorption units (Abs) per cm.

Three samples of new (virgin) test oil were submitted to establish a baseline. These samples had values for both oxidation and nitration of 0.1 Abs/cm. Essentially, there were no oxidation or nitration products (peaks) on the infrared absorption spectrum plots. The only bus oil analysis performed since initiating the oxidation and nitration testing had an oxidation value of 1.9 Abs/cm and a nitration value of

2.1 Abs/cm. The laboratory performing the analysis tests suggests that a value of 10 Abs/cm for both oxidation and nitration levels is the condemnation limit for motor oil.

## Particle Count Analysis

During the October-December evaluation quarter, a particle count analysis will be added as a one-time test to measure the efficiency of the filter systems. The test laboratory will physically count or quantify the particle sizes in a range of sizes between 2 and 100 microns from a given volume of oil. Oil samples will be pulled from all of the test buses and a few select nontest INEEL buses for a comparative evaluation between the bypass filter system and the factory full-flow filters.

# USED ENGINE OIL DISPOSAL COSTS

A potential factor in the economic life-cycle analysis of the oil bypass filter system is the cost of disposing used engine oil. The costs could include time to manage the used oil and fees for disposal. At the INEEL, the waste generator services personnel stated that they spend less than four hours per year managing the waste oil and generating the paperwork for disposal. Given the volume of oil generated by the INEEL's 99 buses and 1,500 other vehicles, the annual cost per quart or gallon of oil for four hours of labor is not a consideration. It appears that when oil is recycled for refining or burnt to recover the energy, there is minimal oversight required. There are also no fees to the INEEL for allowing waste oil haulers to pick up the oil.

Various DOE facilities were contacted to determine their waste oil disposal costs, and it was found that many of the facilities also pay no or minimal disposal costs. In addition, the vehicles at several DOE facilities are serviced by local automotive dealerships. Therefore, five automotive dealerships were contacted to ascertain their disposal costs.

Table 3 below lists the findings of a limited search of the five automotive dealerships and seven DOE facilities. The search shows that the oil pickup and disposal costs vary from no charge (67% of responses) to $55.00. It should be noted that the pickup charge is the same for one gallon of oil or a full tank of waste oil. While the cost varies between locations, it is either zero or relatively minimal on a per quart basis. Therefore, the cost of used oil pickup and disposal is considered a nonfactor in the economic life-cycle analysis.

Table 3. Costs of used oil disposal

| Location | Waste Oil Pickup Cost |
|---|---|
| Automotive Dealer 1 | Free |
| Automotive Dealer 2 | Free |
| Automotive Dealer 3 | Free |
| Automotive Dealer 4 | $30 |
| Automotive Dealer 5 | $20 |
| Idaho National Engineering and Environmental Laboratory | Free |
| Sandia National Laboratory | Free |
| Brookhaven National Laboratory | Free |
| Nevada Test Site | Free |
| Hanford Laboratory | $55 |
| Y-12 Plant at Oak Ridge | Free |
| Argonne National Laboratory-East | $10 |

## UNSCHEDULED OIL CHANGE

On 9/16/03, the oil in bus 73448 was changed when the service mechanic assigned to change the transmission fluid on the bus inadvertently changed the engine oil instead. An oil analysis sample of the oil was obtained before the oil was drained. Recognizing the error, the mechanic then changed the filters, put in new oil and the test on bus 73448 was restarted. The bus had traveled 25,572 miles without an oil change, and the oil analysis test showed that the oil was still well within usable values. In addition to the several signs/warnings currently used on each bus in the test, other measures are being considered to avoid future servicing errors.

## LIGHT-DUTY VEHICLE FILTER EVALUATION

Installation of oil bypass filter systems is scheduled for six model year 2002 Chevrolet Tahoe sport utility vehicles, to begin during the fourth quarter of 2003. Six puraDYN PFT-8 filter systems (8-quart capacity) with replacement filters are staged in the parts room, and the test plan has been approved for use. The Tahoes are security vehicles subjected to severe service and high mileage, with long periods of idling and multiple drivers. One system will be installed to validate the installation procedure, and then the remainder of the five systems will be installed when the vehicles are scheduled for regular servicing.

In order to establish a historical baseline of engine wear metals, oil analysis specimens are being collected and analyzed on each Tahoe before installation of the oil bypass systems. This will provide a benchmark for each vehicle against which to compare future test results. Nine of the 13 pre-evaluation analyses of the Tahoes report an abnormal condition in the oil. Table 3 shows the disposition of the oil analysis reports and itemizes the abnormal conditions. The oil will continue to be sampled on the Tahoes until at least three samples have been analyzed per vehicle. The intent is to continue using the American Choice partially recycled oil in the Tahoes after the bypass systems are installed. There are obvious gaps in the chart below. Some of the vehicles have not been driven as much as expected, and sometimes the oil sample was not taken when serviced. Steps have been taken to ensure the samples are taken when the vehicles are serviced.

Table 3. Oil condition from the light vehicle oil analysis reports.

| Vehicle | 1st Analysis | 2nd Analysis | 3rd Analysis | 4th Analysis |
|---|---|---|---|---|
| 71326 | Normal | Normal | | |
| 71333 | Normal | Abnormal: 58 ppm Cu[1] | | |
| 71391 | Abnormal: 59 ppm Cu and 1.6 TBN[2] | | | |
| 71394 | Abnormal: 53 ppm Cu | Abnormal: 48 ppm Cu and 100 ppm Na[3] | Normal | Abnormal: 67 ppm Cu |
| 71400 | Abnormal: 59 ppm Cu | | | |
| 71402 | Abnormal: 60 ppm Cu | Abnormal: 73 ppm Cu | Abnormal: 242 ppm Cu and 36 ppm Pb[4] | |

[1]Cu = Copper.
[2]TBN= Total Base Number (the inverse of Total Acid Number).
[3]Na = Sodium.
[4]Pb = Lead.

## SUMMARY

Eight puraDYN PFT-40 (40-quart capacity) oil bypass filter systems are being tested on eight INEEL buses. To date, the eight buses have accumulated 259,398 miles. With a 12,000-mile servicing schedule, this represents an avoidance of 21 oil changes, which equates to 740 quarts of oil saved (185 gallons).

After the 259,398 miles, none of the bus oils were changed because of being out of specification or in a degraded condition.

A factor in the economic life-cycle analysis is the cost of disposing used oil. It has been identified that most of the DOE facilities and private oil generators pay no, or minimal, disposal costs. Therefore, the cost of used oil disposal appears to be a nonfactor in the economic life-cycle analysis of oil bypass filter systems.

There is a trend of high ppm of iron in bus 73450, but the quality of the oil is still acceptable. In addition, when the iron levels are examined on a wear-rate ratio basis (ppm of iron per 1,000 miles traveled) after 58,807 miles, the overall wear rate ratio has remained fairly consistent; therefore, the oil is considered to still be useable.

In the next testing quarter, a particle count will be added to the suite of tests to measure the efficiency of the filter systems. The test laboratory will physically quantify the particle sizes in a range of between 2 and 100 microns from a given volume of oil. Oil samples will be pulled from all of the test buses and a few INEEL nontest buses for a comparative evaluation.

Additional tests of oxidation and nitration analysis were added to the suite of tests to measure fitness of the oil, and the data will be tracked.

The light-duty vehicle filter system installation and evaluation will begin after three oil analysis reports are completed for each vehicle.

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