INEEL/EXT-04-02486

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

## Oil Bypass Filter Technology Evaluation Eight Quarterly Report July – September 2004

Larry Zirker
James Francfort
Jordan Fielding

November 2004

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 Oil Bypass Filter Technology Evaluation quarterly report (July–September 2004) details the ongoing fleet evaluation of an oil bypass filter technology being conducted by the Idaho National Engineering and Environmental Laboratory (INEEL) for the U.S. Department of Energy's FreedomCAR & Vehicle Technologies Program. Eight INEEL four-cycle diesel-engine buses used to transport INEEL employees on various routes and six INEEL Chevrolet Tahoes with gasoline engines are 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.

This quarter, the eight diesel engine buses traveled 82,123 miles. As of the end of September 2004, they had accumulated 580,848 miles since the beginning of the test and 516,401 miles without an oil change. This represents an avoidance of 43 oil changes, which equates to 1,505 quarts (376 gallons) of new oil not consumed and 1,505 quarts of waste oil not generated. Two buses had their oil changed this quarter due to the degraded quality of the engine oil, as determined by low total base numbers.

The six Tahoe test vehicles traveled 40,762 miles. As of the end of September 2004, the Tahoes had accumulated 150,205 total test miles. The Tahoe filter test is in transition, however, because the engines are being cleaned/flushed, and the recycled oil used from the outset of testing is being replaced with virgin 10W-30 Castrol oil. Three Tahoes have been flushed to date and testing restarted.

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# Oil Bypass Filter Technology Evaluation
# Eighth Quarterly Report

## INTRODUCTION AND BACKGROUND

This Oil Bypass Filter Technology Evaluation quarterly report covers the evaluation period July through September 2004. PuraDYN oil bypass filter systems (Figure 1) are being tested on eight diesel buses and six Chevrolet Tahoes (eight-cylinder gasoline engines) in the Idaho National Engineering and Environmental Laboratory (INEEL) fleet. Typically, the INEEL buses travel established routes, carrying workers during their morning and evening trips to and from the INEEL test site (100+ miles per round-trip). The Tahoes are used within the 900 square mile INEEL site or between the INEEL site facilities and Idaho Falls, Idaho, a distance of 50 miles each way. This work is being performed for the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program.

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

- Three buses with Series 50 Detroit diesel engines
- Four buses with Series 60 Detroit diesel engines
- One bus with a Model 310 Caterpillar engine.

This quarterly report covers the following:

- Status of bus mileage and performance
- Analysis and reporting of bus engine oil
- Oil use
- Lessons learned on the heavy vehicles
- Upcoming INEEL tests
- Oil bypass filter system manufactures
- Status of light-duty vehicle mileage and performance
- Lessons learned from the evaluation of light-duty vehicles.

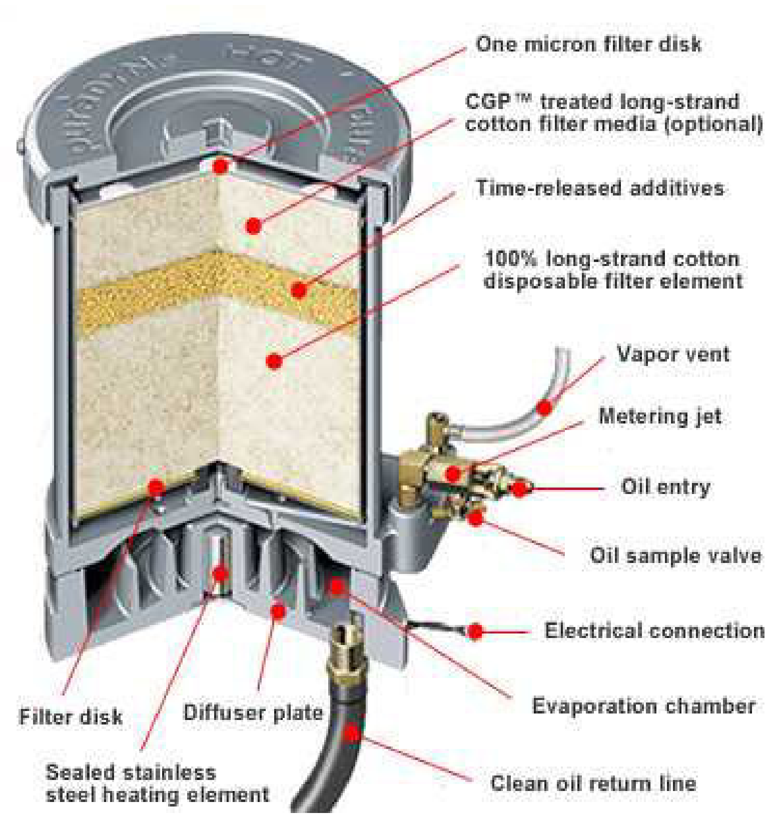


Figure 1. Cutaway of a puraDYN oil bypass filter.

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

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

| Reporting Quarter | Report Number | Major Topics |
|---|---|---|
| Oct 2–Dec 2 2002 | INEEL/EXT-03-00129 | • Background on fleet operations, vehicles, filters, and oil selection<br>• Performance evaluation status<br>• Economic analysis<br>• Photographs of installed systems<br>• Bypass Filtration System Evaluation Test Plan |
| Jan 3–Mar 3 2003 | INEEL/EXT-03-00620 | • Background on reports<br>• Bus mileage and performance status<br>• Revised filter replacement schedule<br>• Oil-analysis sampling<br>• Light-duty vehicle test status |
| Apr 3–Jun 3 2003 | INEEL/EXT-03-00974 | • Background on reports<br>• Bus mileage and performance status<br>• Preliminary trends in oil analysis reports<br>• Revised economic analysis<br>• Ancillary data<br>• Light-duty vehicle test status |
| Jul 3–Sep 3 2003 | INEEL/EXT-03-01314 | • Background on prior quarterly reports<br>• Bus mileage and performance status<br>• Used engine-oil disposal costs<br>• Unscheduled oil change<br>• Light-duty vehicle test status |
| Oct 3–Dec 3 2003 | INEEL/EXT-04-01618 | • Bus mileage and performance status<br>• Bus oil analysis testing and reporting<br>• Light-duty vehicle filter installations<br>• Light-duty vehicle filter installations lessons learned<br>• Light-duty vehicle filter evaluation status |
| Jan 4–Mar 4 2004 | INEEL/EXT-04-02004 | • Bus mileage and performance status<br>• Bus oil analysis testing and reporting<br>• Bus engine oil particulate count analysis<br>• Light-duty vehicle mileage and performance status<br>• Light-duty vehicle filter evaluation lessons learned |
| Apr 4-Jun 2004 | INEEL/EXT-04-02194 | • Bus mileage and performance status<br>• Bus oil analysis testing and reporting<br>• Lessons learned from the evaluation of heavy-vehicle filters<br>• Light-vehicle mileage and performance status<br>• Lessons learned from the evaluation of light-vehicle filters |

# HEAVY-VEHICLE TESTING

## Status of Bus Mileage and Performance

During this reporting quarter (July–September 2004), the eight diesel-powered buses traveled 82,123 miles. Fewer miles (3,509) were travel this quarter (compared to the April–June quarter) mainly because bus 73425 was disabled for a few weeks by a transmission seal failure unrelated to the bypass filter evaluation. Figure 2 shows the quarterly and cumulative evaluation miles. Table 2 details the mileage status of the eight test buses. Figure 3 shows the total evaluation miles per bus, by evaluation quarter.

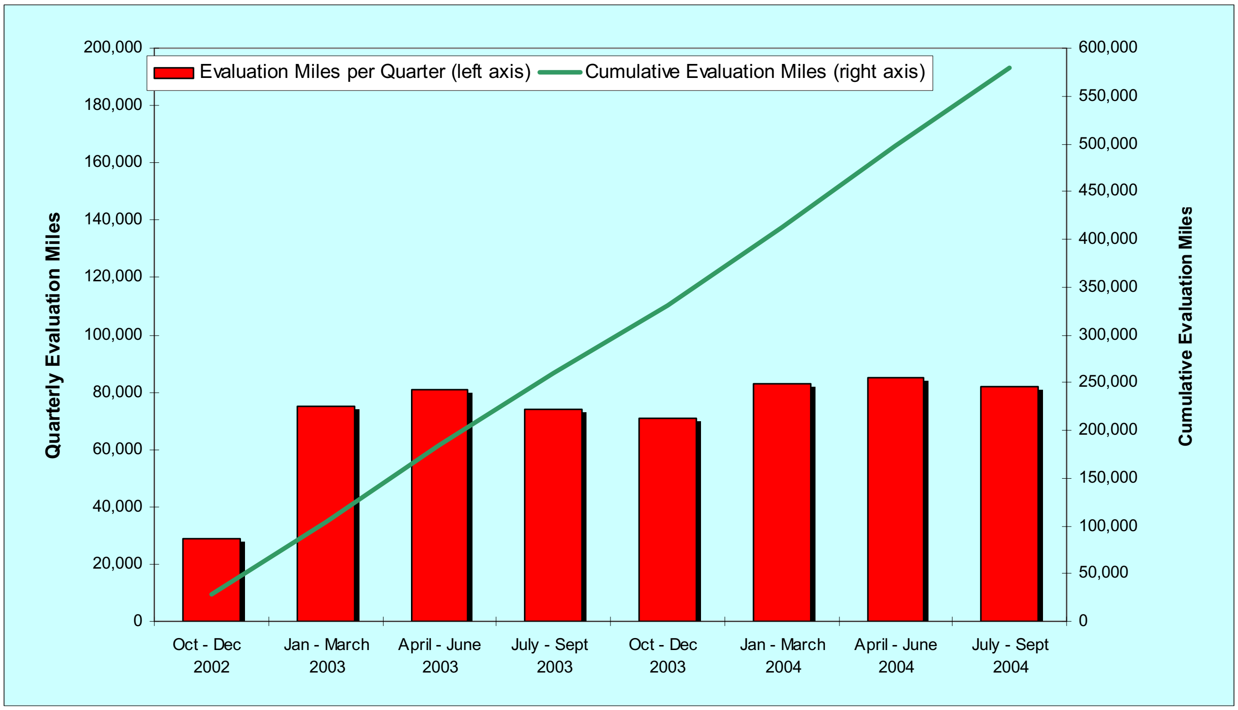


Figure 2. Quarterly and cumulative miles traveled by the test buses.

Table 2. Test buses and test mileage on the bus engine oil as of September 30, 2004.

| Bus Number | Test Start Date | Bus Mileage at Start Date | Current Mileage (Sept. 30) | Total Test Mileage | Mileage on Initial Oil (Sept. 30) | Miles on Current Oil (Sept. 30) |
|---|---|---|---|---|---|---|
| 73425 | Dec 18, 2002 | 41,969 | 89,203 | 47,234 | 47,234 | 47,234 |
| 73432 | Feb 11, 2003 | 47,612 | 121,605 | 73,993 | 73,993 | 73,993 |
| 73433 | Dec 4, 2002 | 198,582 | 277,036 | 78,365 | 78,365 | 78,454 |
| 73446[1] | Oct 23, 2002 | 117,668 | 182,432 | 64,764 | 53,194 | 11,570 |
| 73447[1] | Nov 14, 2002 | 98,069 | 158,588 | 60,519 | 54,201 | 6,318 |
| 73448[2] | Nov 14, 2002 | 150,600 | 208,247 | 57,647 | 25,572 | 32,075 |
| 73449 | Nov 13, 2002 | 110,572 | 165,274 | 54,702 | 54,702 | 54,702 |
| 73450[1] | Nov 20, 2002 | 113,502 | 257,126 | 143,624 | 129,140 | 14,484 |
| | | | | 580,848[3] | 516,401[4] | 318,741[3] |

[1] The oil bus was intentionally changed due to degraded oil quality, determined by low total base numbers.

[2] The oil on bus 73448 was inadvertently changed on September 16, 2003.

[3] The total bus test miles are 580,848 miles.

[4] The total bus test miles without an oil change.

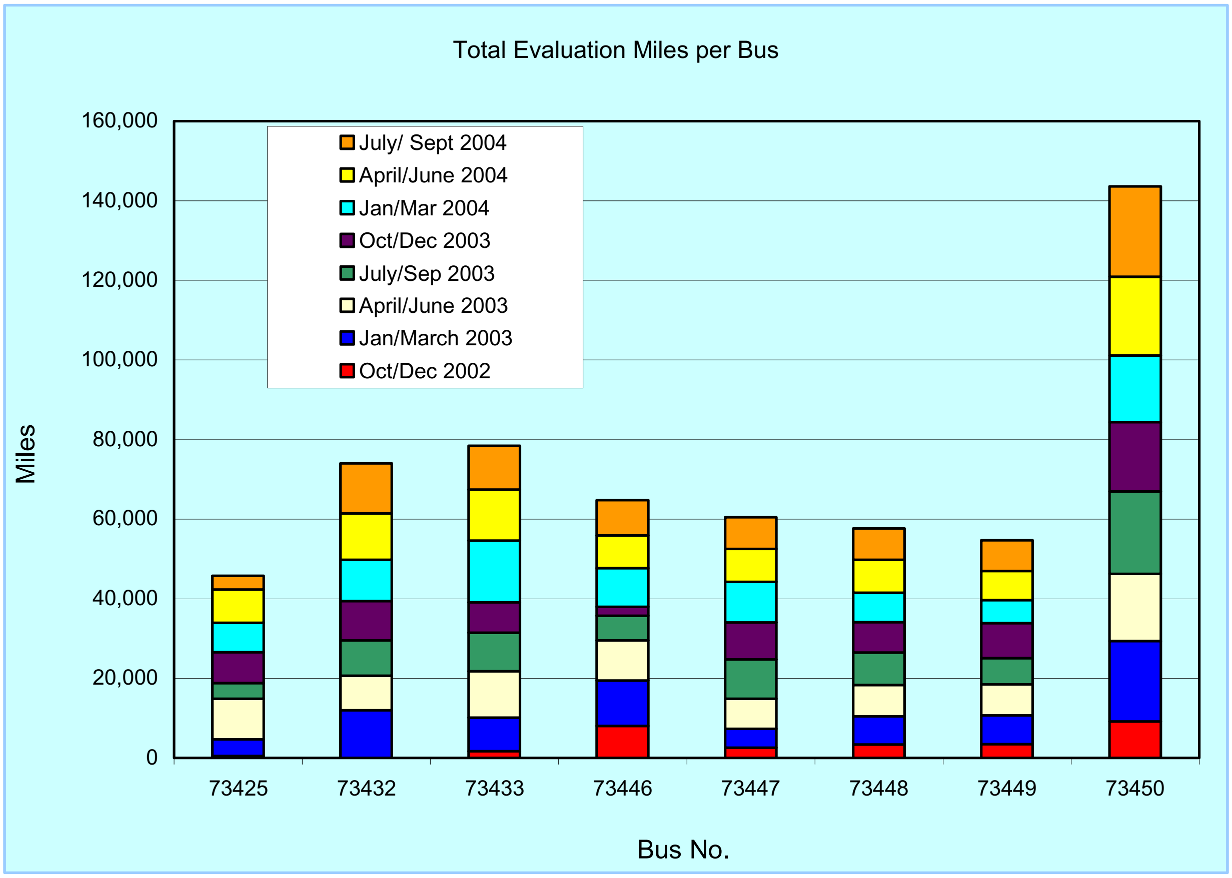

Figure 3. Total evaluation miles by bus for the July–September 2004 quarter.

## Analysis and Reporting of Bus Engine Oil

Five oil-services occurred this quarter, and all bus oils were within acceptable operating limits. To date, declining total base number (TBN) quality values has condemned the oil of three buses. Since two oil analyses are conducted for each oil-servicing, two TBN values are reported—one from each of the two oil analysis laboratories. As stated in previous reports, a TBN value less than 3.0 mgKOH/g has been determined as the condemnation point. With two laboratories, sometimes the value will be less than 3.0 for one laboratory and greater that 3.0 for the other. In such a case, the two values are averaged and an oil change is ordered if the average value for the two reports is below 3.0. The TBN indicates the acid reducing value of the oil.

## Oil Use

The oil use for each bus has been tracked since the oil bypass filter technology evaluation began. Oil use consists of (1) oil that is added periodically to a bus engine when the oil is checked daily and the oil level is low, and (2) oil that is added to the bus engine to replenish the oil lost when the full-flow or bypass oil filter is changed. A log sheet is kept in a clear plastic envelop attached to the inner wall of the cargo bay near the containers of Shell Rotella-T, 15W-40 oil used for this evaluation. The bus drivers (who fuel the buses and check the engine oil levels daily) and the service mechanic were asked to update the log sheet when oil is added to the bus engines. The following table shows the total oil consumption for each bus since this oil bypass filter evaluation began.

Table 3. Oil use as of September 30, 2004.

| | Bus | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test Data | 73425 | 73432 | 73433 | 73446 | 73447 | 73448[9] | 73449 | 73450[10] |
| Test start date[1] | 12/18/02 | 2/11/03 | 12/4/02 | 10/23/02 | 11/14/02 | 11/14/02 | 11/13/02 | 11/20/02 |
| Volume of oil pan[2] | 28 | 28 | 28 | 40 | 40 | 40 | 40 | 38 |
| Miles on oil[3] | 47,234 | 73,993 | 78,365 | 53,194 | 54,201 | 57,942 | 54,995 | 129,140 |
| Status of test[4] | Ongoing | Ongoing | Ongoing | 6/2/04 | 8/3/04 | 9/16/03 | Ongoing | 8/31/04 |
| Daily oil check top-off[5] | 27 | 60 | 80 | 13 | 20 | 13 | 13 | 63 |
| Filter service makeup oil[6] | 29 | 44 | 47 | 38 | 32 | 28 | 27 | 40 |
| Total oil added[7] | 56 | 104 | 127 | 51 | 52 | 41 | 40 | 103 |
| Oil replacement ratio[8] | 2.0 | 3.7 | 4.5 | 1.3 | 1.3 | 1.0 | 1.0 | 2.7 |
| Oil use per 1,000 miles | 1.2 | 1.4 | 1.6 | 1.0 | 1.0 | 0.7 | 0.7 | 0.8 |

[1] Date the bypass filter system and the new 15W-40 Shell Rotella-T oil were installed in the bus.

[2] Total volume capacity, in quarts, of the diesel engine oil pan.

[3] The miles traveled since the initial charge of oil at the beginning of the test (if the bus is still traveling on the initial charge of oil), or the miles since the initial charge to when the initial oil was changed.

[4] The status of the test is either "ongoing" (if the bus is still traveling on the initial charge of oil), or the date the initial test oil was changed.

[5] Volume of oil, in quarts, added during the daily oil check up to 9/30/04 or to the date the initial oil was changed.

[6] Volume of oil, in quarts, added to provide the make-up oil when the filters are changed during servicing up to 9/30/04 or to the date that the initial oil was changed. On some buses, the volume added during the filter servicing was not recorded on the oil use log; therefore, an average volume of seven quarts was substituted for the missed servicing. Seven quarts were derived, because the volume added for filters varied between 4 and 10 quarts.

[7] Total quarts of oil added to the system since the start of the test activity up to 9/30/04 or to the date the initial oil was changed (sum of the above two lines).

[8] The oil replacement ratio is the amount (in quarts) of oil added during the filter evaluation project divided by the size of the engine oil pan.

[9] The oil on bus 73448 was inadvertently changed on 9/16/03. Since this chart tracks daily and filter service oil use, Bus 73448 values include all the miles traveled and oil used to date, but do not include the oil change on 9/16/03.

[10] The oil-use log for bus 73450 is incomplete. Only data for 9 months of 2004 are available. The daily top-off and filter make-up oil for the 9 months of 2004 were used to extrapolate the volume of oil used for 2003.

During the oil bypass filter evaluation, oil analysis reports document the oil quality as the oil ages. However, the quality (such as TBN) of the engine oil in the buses can be enhanced by regular multi quart infusions of fresh oil to the oil supply system. The oil quality of a leaking engine with a premium oil bypass filter system may not degrade because the regularly added oil bolsters the oil values. But if an engine is new or otherwise does not consume oil, the oil values may degrade faster, not being replenished. The INEEL buses used in this evaluation are equipped with the newest engines in the fleet and were the only four-cycle diesel engines at the time the puraDYN oil bypass filters were installed.

Some interesting facts are evident in Table 3. Buses 73425, 73432 and 73433 have four-cylinder Detroit Diesel (DD) engines, whereas the other buses have six-cylinder engines. Looking at the oil use as measured by the oil replacement ratio, these four-cylinder DD engines have greater oil use than the six-cylinder DD engines. The volume replacement in respect to the oil pan volume capacity varies between 2.0 and 4.5 times for the four-cylinder DD engines, whereas the six-cylinder DD engine oil volume replacement in respect to the oil pan volume capacity varies between 1.0 and 1.3 times.

The oil use per 1,000 miles driven for the three four-cylinder engines ranged between 1.2 and 1.6 quarts per 1,000 miles driven. For the five six-cylinder engines, oil use per 1,000 miles varied between 0.7 and 1.0 quarts per thousand miles. The two buses with the highest oil use, 73432 (104 quarts) and 73433 (127 quarts), also have the two highest TBN values (high is good), 7.1 and 8.3. Of the six-cylinder engines, only one is still operating on its initial charge of oil—bus 73449. All of the other engine oils have been changed due to a drop in TBN below 3.0.

Another point of interest is the comparison in average iron parts per million (ppm) test results between the four- and the six-cylinder DD engines (Table 4).

Table 4. Averaged iron parts per million (ppm) from all oil analysis reports.

| Bus | Averaged Iron Values (ppm) |
|---|---|
| Four cylinder - 73425 | 80 |
| Four cylinder - 73432 | 46 |
| Four cylinder - 73433 | 89 |
| | |
| Six cylinder - 73446 | 29 |
| Six cylinder - 73447 | 30 |
| Six cylinder - 73448 | 14 |
| Six cylinder - 73449 | 22 |

Table 4 shows that the ppm of iron for the four-cylinder engines is significantly higher than for the six-cylinder engines. In discussing this finding with the fleet operations personnel, the only explanation is that the four-cylinder engines are working harder and thus getting more wear and consuming more oil.

## Lessons Learned on the Heavy Vehicles

The several lessons learned from this quarter's work are discussed below.

### Cross-Training of Service Personnel

This is the eighth quarterly report, and the regular bus service mechanic religiously takes the oil analysis samples and sends them to the two testing laboratories. However, a recent review of the service events revealed that both oil analysis reports for one of the bus service events was missing. Sometimes a sample is lost in the mail, and the archive sample is sent to the test laboratory to complete the data. However, never have both samples been lost. Checking the records and the archive sample cabinet revealed that no archive sample exists. It was concluded that no oil analysis samples were taken during the service. When the service mechanic was questioned about the missed oil analysis samples for the date of service, he explained that he was out with a neck injury during that week. The lesson learned is that effort must be taken to ensure that fleet management instruct substitute workers of all tasks involved with servicing oil bypass filters and the vehicles that operate with them.

### Makeup Oil Can Influence Oil Quality

The oil use on the test bus vehicles was tabulated. The two buses with the highest TBN values (higher is better) are buses that have the highest volume of oil being added in between the filter servicing events. As would be expected, adding larger volumes of replacement oil to the oil supply system appears to keep the oil quality value of TBN higher.

## Upcoming INEEL Tests

Two tests or evaluations will be added to the INEEL heavy-vehicle testing regimen.

### Diesel Engine Idling Wear-Rate Evaluation Test

A diesel engine wear-rate evaluation will be undertaken to support DOE's effort to minimize diesel engine idling in the United States and the associated annual consumption of over 850 million gallons of diesel fuel during periods of engine idling for heating, cooling, and auxiliary power generation purposes. In addition to the economic advantage of minimizing the use of fuel by avoiding engine idling, there are other possible economic advantages if engine life can be extended and maintenance intervals lengthened.

The INEEL proposes to characterize diesel engine wear and any lubricating degradation due to extended periods of engine idling versus "normal" engine operations by idling two INEEL buses equipped with Detroit Diesel Series 50 engines for 1,000 hours each. The engine wear metals will be characterized by analyzing the engine oil and by destructively analyzing the bypass and full flow filters to measure the engine wear metal particles captured. The two INEEL fleet buses were selected because:

- The two buses are part of the Oil Bypass Filter Evaluation program
- Their engine wear patterns have been monitored for 20+ months
- The two buses are equipped with four-cycle engines
- The two buses have a documented history of maintenance and fuel usage
- INEEL Fleet Operations provides consistent and scheduled maintenance of these buses.

### Refined Global Solutions Filter Evaluation

The ongoing oil bypass filter technology evaluation is being expanded to include oil bypass filters from Refined Global Solution (RGS), Inc., of Bluffdale, Utah. It is proposed during the next quarter to install RGS FP-1000 bypass filter systems on three INEEL fleet buses with recently refurbished four-cylinder, four-cycle diesel engines. This will expand the bypass filter evaluation from eight to eleven buses.

## Oil Bypass Filter System Manufactures

A recent literature search identified several U.S. oil bypass filter manufacturing companies, the list of which is shown in Appendix A. (If the list is incomplete, it is an oversight. To update the list, please forward any comments or changes to fieljj@inel.gov.) If necessary, a revised list will be published in the future.

# LIGHT-VEHICLE TESTING

## Status of Light-duty Vehicle Mileage and Performance

During this reporting quarter, the six light-duty Tahoe test vehicles traveled 40,762 miles, accumulating 150,205 total test miles. Owing to the low oil qualities from extended use, the recycled oil

(Americas Choice 10W-30) was replaced with Castrol 10W-30 oil. By changing from one brand of oil to another, with different detergent values, it was anticipated a more pronounced cleaning action by the new oil and engine gunk left by the previous oil would be removed. It was planned to operate the Tahoes for one 3,000-mile service interval with the new Castrol oil to clean the engine, then change the Castrol oil and replace it with new Castrol oil and oil filters. It was discovered that the oil needed to be changed twice before getting stable oil quality data (determined by TBN testing). Three vehicles to date have undergone this double cleaning process, and testing will resume when the TBN values improve. Details on the performance of filters and oil in the Tahoes will be reported next quarter.

## Lessons Learned from the Evaluation of Light-Duty Vehicles

### Maintenance Tracking System

Recently, one of the Tahoes was inadvertently serviced twice in one week. The INEEL fleet maintenance facility uses commercially available software to manage and track the fleet maintenance. When the mechanic completes work on a vehicle, he submits the completed electronic work order(s) into the fleet maintenance system. Sometimes, the software does not update itself for a day or two. Also, there are cells within the electronic work orders for mechanics to make notes or comments regarding their activities. When vehicle oil analysis reports were being reviewed, it appeared that one of the Tahoes had missed a service and there was no notation by the mechanic that the oil was changed. Since this vehicle was in the engine flushing cycle and it was not clear to the mechanic foreman and the filter test engineer that the service had been performed, this Tahoe was called in and the backup oil service mechanic immediately changed the oil again. When the second work order was updated into the maintenance database, it was noted that the regular service mechanic had serviced the vehicle two days earlier. Now, to avoid duplication in servicing, the mechanic foreman and the test engineer check with the work order schedulers when it appears that a vehicle has missed a service interval before they order any immediate service work.

# SUMMARY

PuraDYN PFT-40 (40-quart capacity) oil bypass filter systems are being tested on eight INEEL buses. To date, the eight buses have accumulated 580,848 miles since testing began, and 516,401 miles have been accumulated without an oil change. With a 12,000-mile servicing schedule, this represents an avoidance of 43 oil changes, which equates to 1,505 quarts (376 gallons) of new oil not consumed and 1,505 quarts of waste oil not generated.

The oil on two buses 73447 and 73450 were changed due to low TBN numbers (<3.0 mgKOH/g). The buses were serviced with new filters and a change of oil, and restarted in the evaluation.

Six puraDYN PFT-8 (8-quart capacity) oil bypass filter systems are being tested on six Chevrolet Tahoe vehicles. This quarter, these light-duty Tahoe test vehicles traveled 40,762 miles, accumulating 150,205 total test miles.

No new data are presented for the oil bypass filters on the Tahoes, as the engines are going through a cleaning/flushing stage. The last several oil analysis reports indicate mixed TBN values: some below 3.0, others above 3.0. The oil will continue to be changed until the reports consistently show improved TBN values before restarting the test with the Tahoes.

The three four-cylinder diesel engines have an oil use per 1,000 miles rate that ranges between 1.2 and 1.6, whereas the five six-cylinder engines have an oil use per 1,000 miles rate that ranges between 0.7 and 1.0.

The three four-cylinder Detroit Diesel engines have higher averages of iron ppm (46 to 80 ppm) than the average iron ppm (14 to 30 ppm) of the four six-cylinder Detroit Diesel engines.

The higher oil use and higher rate of iron particulates in the oil of the four-cylinder engines is likely the result of the four-cylinder engines working harder than the six-cylinder engines.

# APPENDIX A

## Oil Bypass Filter System Manufactures

| Bypass Filter Manufacturer | Address | Website |
|---|---|---|
| Amsoil | AMSOIL Building<br>Superior, WI. 54880 | http://www.amsoil.com |
| C.C. Jensen | 1557 N.W. Ballard Way<br>Seattle, WA. 98107 | http://ccjensen.com |
| Enviro Kleen | 3186 Grande Oak Pl.<br>Lancaster, PA. 17601-1246 | http://envirokleen.org |
| Filtration Solutions Worldwide | 230 North Monroe<br>Olathe, KS. 66061 | http://filtrationsolutionsww.com |
| Gulf Coast Filters | P.O. Box 2787<br>Gulfport, MS. 39505 | http://www.gulfcoastfilters.com |
| Oil Guard | 3230-B Production Ave.<br>Oceanside, CA. 92054 | http://www.oilguard.com |
| Oil Purification Systems | 205 S. Hoover Blvd. Suite 207<br>Tampa, FL. 33609 | http://oilpursys.com |
| Premo Lubrication Technologies | 13470 Wright Circle<br>Tampa, FL. 33626 | http://www.premolube.com |
| PuraDYN | 2017 High Ridge Rd.<br>Boynton Beach, FL. 33426 | http://www.puradyn.com |
| Refined Global Solutions | 142852 S. Heritagecrest Way,<br>Suite C<br>Bluffdale, UT 84065 | http://www.rgsoilrig.com |
| We Filter It | 2422 12th Avenue Rd. #264<br>Nampa, ID. 83686-6300 | http://www.wefilterit.com |