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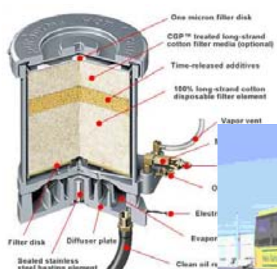
U.S. Department of Energy
FreedomCAR & Vehicle Technologies Program

Oil Bypass Filter Technology Evaluation Fifth Quarterly Report October - December 2003



TECHNICAL REPORT

Larry Zirker
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February 2004

Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

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ABSTRACT

This Oil Bypass Filter Technology Evaluation quarterly report (October–December 2003) 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 324,091 test miles. This represents an avoidance of 27 oil changes, which equates to 952 quarts (238 gallons) of new oil not conserved and therefore, 952 quarts of waste oil not generated. To validate the extended oil-drain intervals, an oil-analysis regime is used to evaluate the fitness of the oil for continued service by monitoring the presence of necessary additives, undesirable contaminants, and engine-wear metals. The test fleet has been expanded to include six Chevrolet Tahoe sport utility vehicles with gasoline engines.

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Fifth Quarterly Report

INTRODUCTION AND BACKGROUND

This Oil Bypass Filter Technology Evaluation quarterly report covers the evaluation period October through December 2003.[1] Eight puraDYN PFT-40 (40-quart capacity) oil bypass filter systems (Figure 1) are being tested on 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.

In addition to the eight buses, oil bypass filter systems were installed on six light-duty Chevrolet Tahoes, and oil testing has been initiated on the Tahoes.

This quarterly report covers the following:

- Bus mileage and performance status
- Bus engine oil analysis testing and reporting
- Light-duty vehicle filter installations and lessons learned
- Summary.

A list of the first year's reports and the major topics in each report is presented in Table 1.

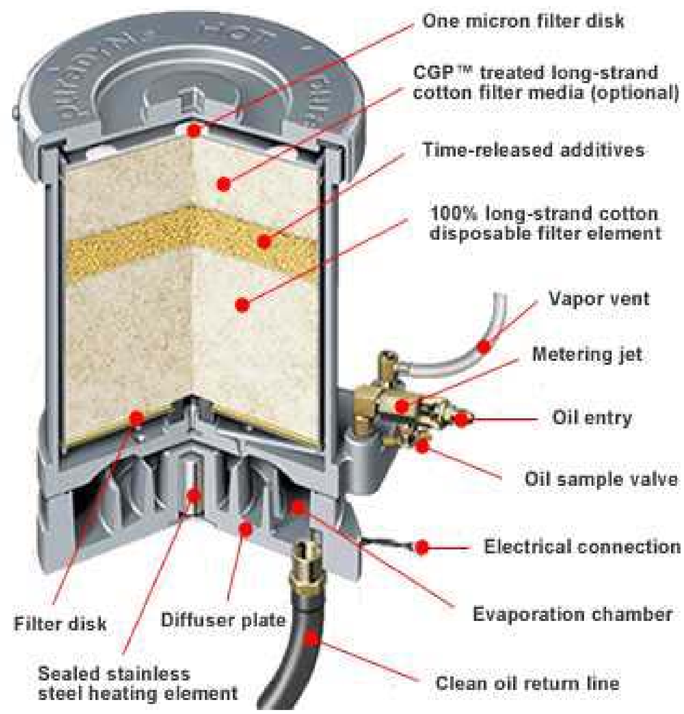

Figure 1. Cutaway of a puraDYN oil bypass filter

BUS TESTING ACTIVITIES

Bus Mileage and Performance Status

During this reporting quarter (October—December 2003), the eight buses traveled approximately 74,410 miles (Figure 2). This total is less than last quarter by 9,713 miles. During this quarter, one bus accumulated more miles than the previous quarter; two buses accumulated about the same number of miles, and five buses accumulated fewer miles than the previous quarter. One of the test buses (73446) underwent extensive repairs (unrelated to the oil bypass system), which significantly reduced mileage accumulation.

[1] The U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program funds this activity.

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). Table 2 details the mileage status of the eight test buses. Figure 3 shows the total evaluation miles per bus, by evaluation quarter.

Table 1. Quarterly reports, dates covered, and major topics covered. All of the reports are available online at the following address: http://avt.inel.gov/obp.html

Reporting Quarter	Report Number	Major Topics
10/02 – 12/02	INEEL/EXT-03-00129	• Background on fleet operations, vehicles, filters, and oil selection • Performance evaluation status • Economic analysis • Photographs of installed systems • Bypass Filtration System Evaluation Test Plan
1/03 – 3/03	INEEL/EXT-03-00620	• Background on reports • Bus mileage and performance status • Revised filter replacement schedule • Oil analysis sampling • Light-duty vehicle test status
4/03 – 6/03	INEEL/EXT-03-00974	• Background on reports • Bus mileage and performance status • Preliminary trends in oil analysis reports • Revised economic analysis • Ancillary data • Light-duty vehicle test status
7/03 – 9/03	INEEL/EXT-03-01314	• Background on prior quarterly reports • Bus mileage and performance status • Used engine oil disposal costs • Unscheduled oil change • Light-duty vehicle test status

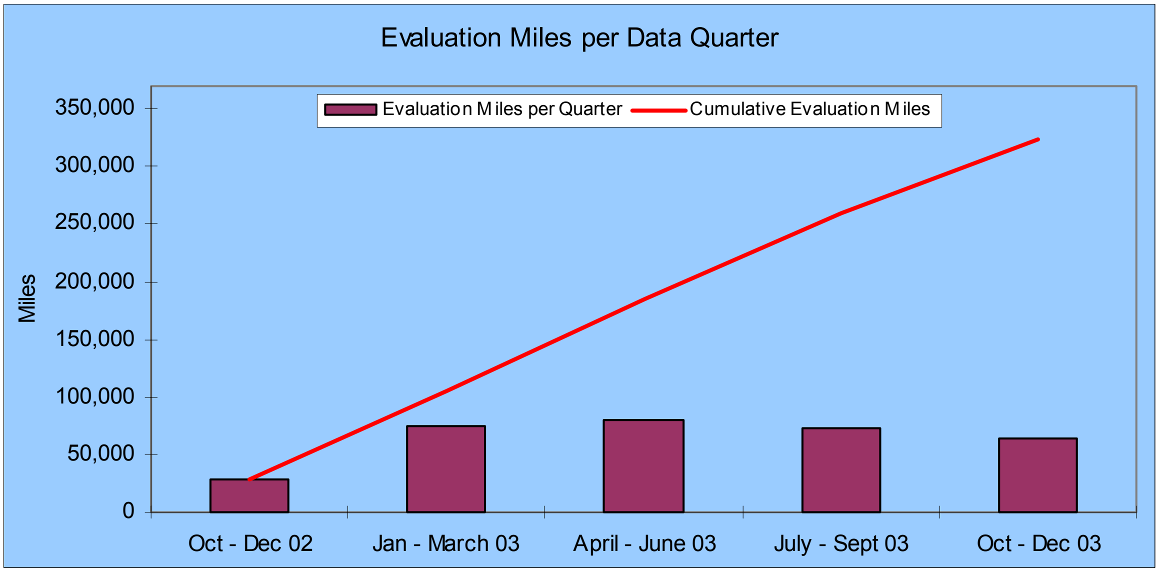

Figure 2. Quarterly and cumulative evaluation miles per evaluation quarter.

Table 2. Test buses and test mileage on the bus engine oil as of January 5, 2004.

Bus Number	Test Start Date	Bus Mileage at Start Date	Current Bus Mileage (1/5/04)	Total Oil Evaluation Test Miles
73425	12/18/2002	41,969	65,301	23,332
73432	2/11/2003	47,612	86,666	39,054
73433	12/4/2002	198,582	237,673	39,002
73446	10/23/2002	117,668	155,639	37,971
73447	11/14/2002	98,069	132,134	34,065
73448	11/14/2002	150,600	184,741	34,137[1]
73449	11/13/2002	110,572	142,756	32,184
73450	11/20/2002	113,502	197,848	84,346
			Total (1/5/04)	324,091

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

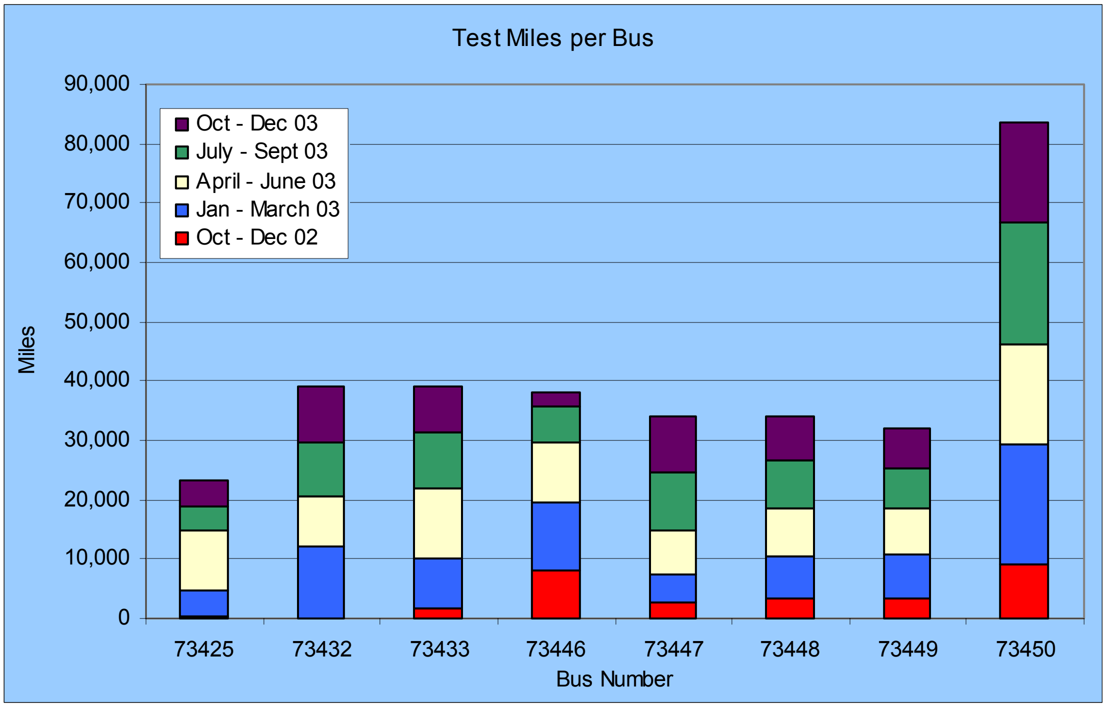

Figure 3. Total evaluation miles per bus by testing quarter.

Bus Oil Analysis Testing and Reporting

As of the end of December 2003, 57 oil analysis reports for the eight buses had been generated—32 from one oil analysis laboratory and 25 from the other. These reports represent the empirical data for this evaluation, with the reports from both testing laboratories broken into two sections.

Oil Quality / Physical Properties

One section of the oil analysis reports focuses on the oil quality (also known as the physical properties of the oil), which is determined by measuring for the presence of water and glycol, and determining oxidation and nitration numbers, total base number (TBN), soot content, and viscosity (detailed discussion is found in the appendix of the First Quarterly Report). The above oil quality variables are the metrics for determining definitively the oil quality in the eight test buses, as there are specific values each variable should remain above or below in order to be considered acceptable INEEL diesel engine oil.

The water and glycol parameters have remained unchanged (and acceptable) throughout the testing period, and oxidation and nitration testing has only recently been added, with only one data point collected thus far. The total base number (Figure 4) and soot (Figure 5) metrics are beginning to show negative trends, with the viscosity levels (Figure 6) remaining fairly even. Note that while the engine oil in all of the buses is showing some signs of degradation, it all remains within acceptable quality limits. When viewing Figures 4 through 9, the bottom scale (X axis) in each chart indicates the number of oil test results (1 through 8) graphed for each bus. Generally, the first and second test results for each bus were conducted at 6,000 and 12,000 miles of oil use, and each additional test was conducted at an additional 12,000 test miles per individual bus.

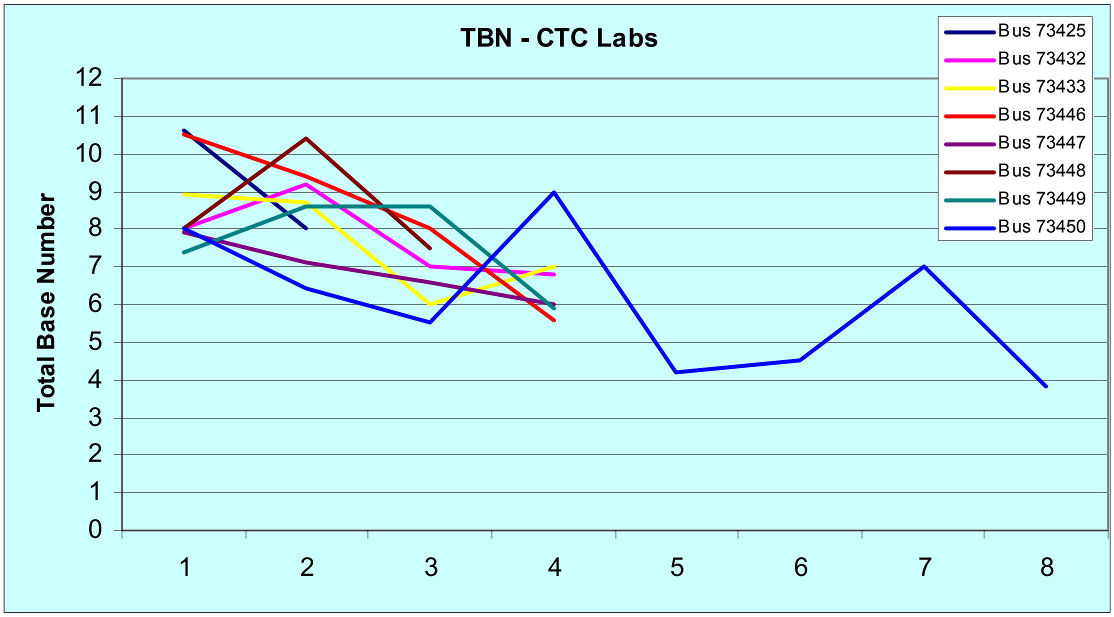

Figure 4. Total base number (TBN) is a measure of the presence of additives that neutralize an acid buildup. A TBN of 3.0 (mgKOH/mL) or below is considered low, and the oil should be changed.

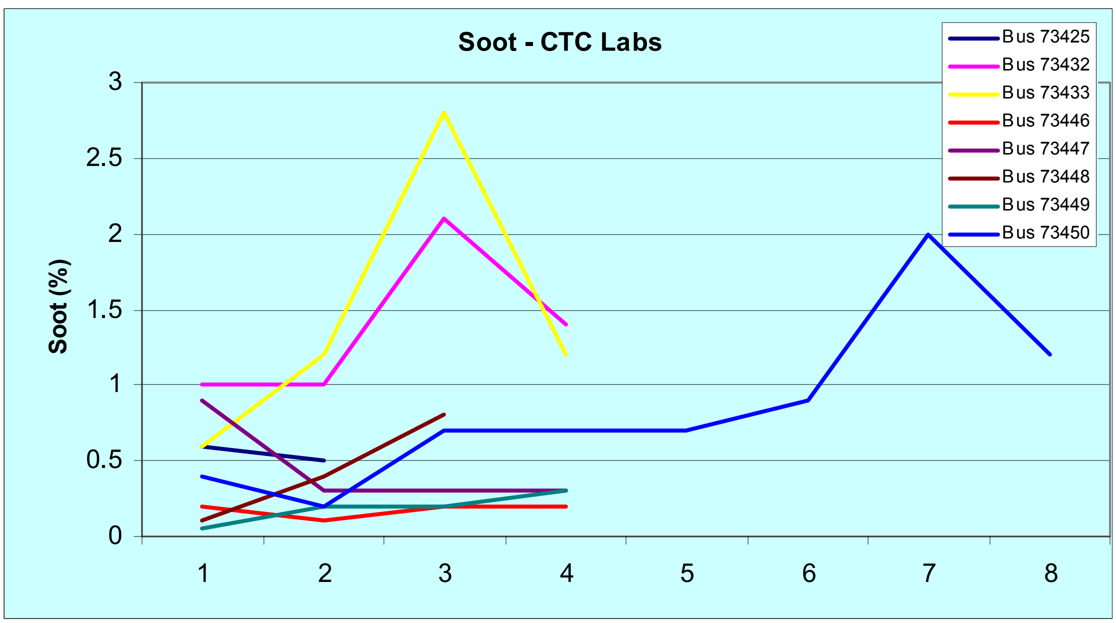

Figure 5. Soot testing measures the presence of solids in the oil from the combustion process. Excessive solids may possibly impair anti-wear benefits and, indirectly, perhaps lead to additional wear above normal for a given engine. Soot levels exceeding 3% indicate the oil should be changed.

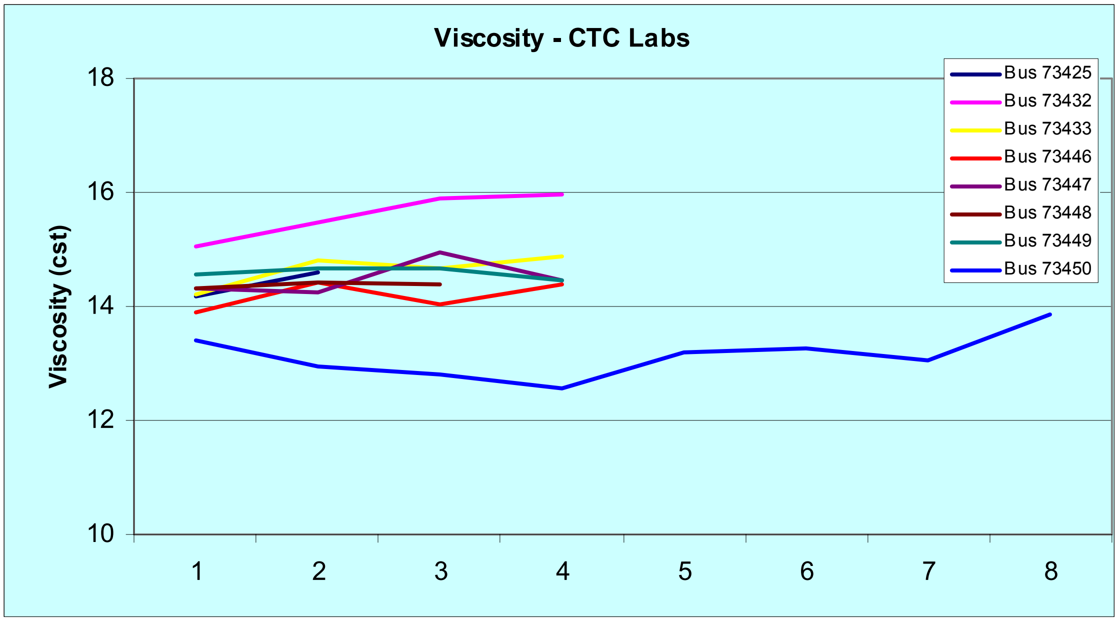

Figure 6. Viscosity is the oil's resistance to flow with respect to temperature as measured in centistokes (cst). The limits for viscosity are based on the SAE grade specified: SAE 30 has a range of 9.29 cst to 12.49 cst, SAE 40 has a range of 12.50 cst to 16.29 cst, and SAE 50 has a range of 16.30 cst to 21.89 cst. The test oil used in the bus engines is 15W-40; all bus oil is within acceptable range.

Spectrochemical / Elemental Analysis

The second section (Spectrochemical / Elemental Analysis) of the oil analysis reports contains the testing results for component wear (such as iron, lead, and copper), airborne dirt (silicon), cooling system contamination (boron, sodium, and potassium), and oil additive concentrations (such as magnesium, calcium, barium, zinc, and molybedenum), as measured in parts per million (ppm).

Component (metal) wear data identify engine parts that are wearing based on the suspended metal(s) in the oil. Iron (Figure 7) is an engine or gear material, whereas lead (Figure 8) and copper (Figure 9) come from bushings and bearings that are wearing. Figures 7 through 9 indicate increasing concentrations of iron, lead, and copper in the engine oils (there are also trends in other metals and chemicals, but only iron, lead, and copper are discussed this quarter). Increases in iron, lead, and copper levels are expected since the metals are accumulating at what is perceived to be a normal pace, with the extended oil use. Because of the extended use of the oil, the test results can be somewhat misleading when viewed conventionally (when the oil is replaced normally at each service interval). With extended oil use, it is believed that the bus engine metals are safely accumulating even while the analysis results suggest high levels of accumulated contaminants.

A wear rate ratio is being used to evaluate the accumulated metal wear levels occurring in the bus oils during the bypass filter evaluation. The wear rate ratio is determined by dividing the total parts per million (ppm) of metal in the oil by each 1,000 miles traveled. If the wear rate remains relatively constant over time, higher total wear metal content is not considered to be harmful. However, if wear rates were to radically increase (double or triple) over consecutive oil tests, then repair action should be taken, i.e., overhaul the engine to remove the failing part before catastrophic failure. Table 3 shows the wear rate of the test buses, except for bus 73448. On 9/15/03, when the transmission fluid was being changed on bus 73448, the engine oil was inadvertently changed. Therefore, there are no current wear-rate-ratio data presented for bus 73448.

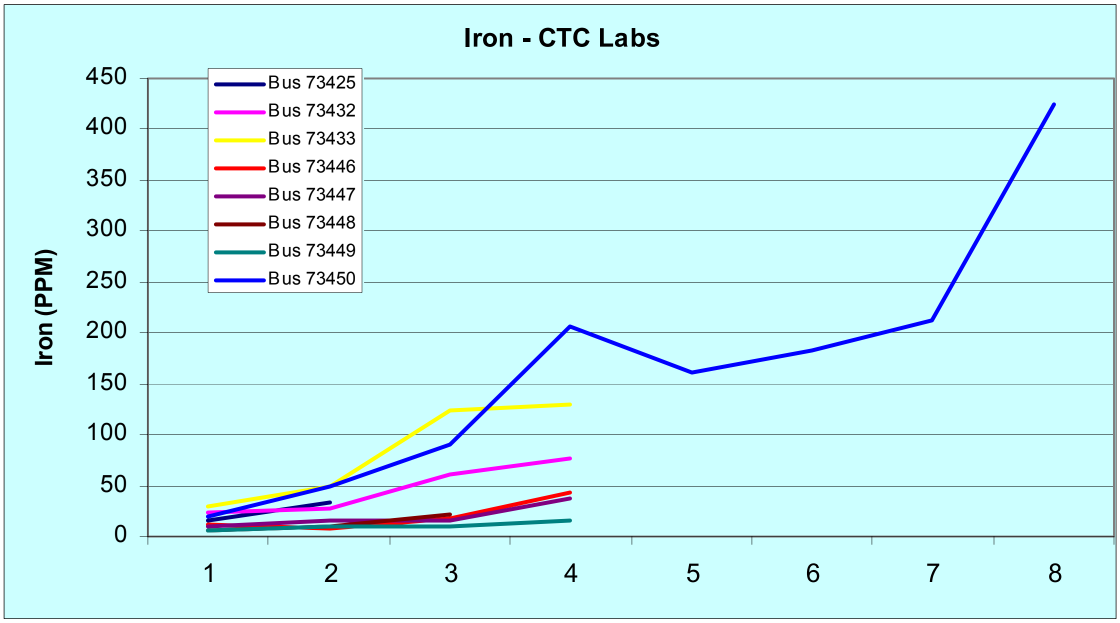

Figure 7. Iron sources include cylinders, gears, rings, crankshafts, liners, bearings, housings, and rust. There is no definitive acceptable range for the presence of iron.

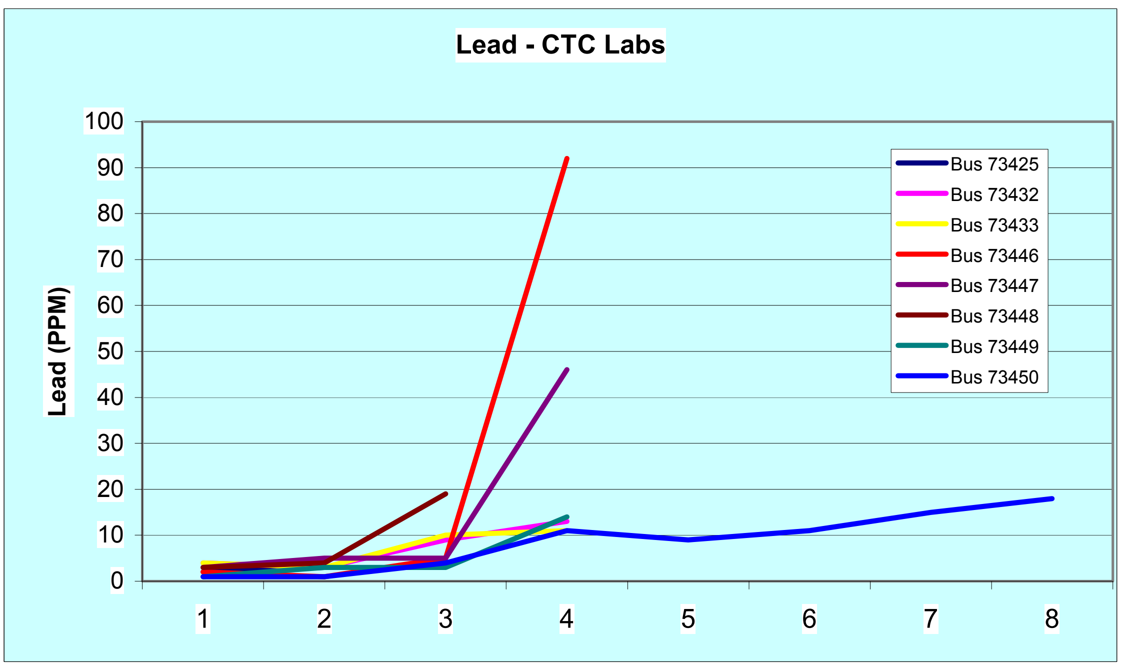

Figure 8. Lead sources include bearing overlays and additives in gear oil and gasoline. There is no definitive acceptable range for the presence of lead.

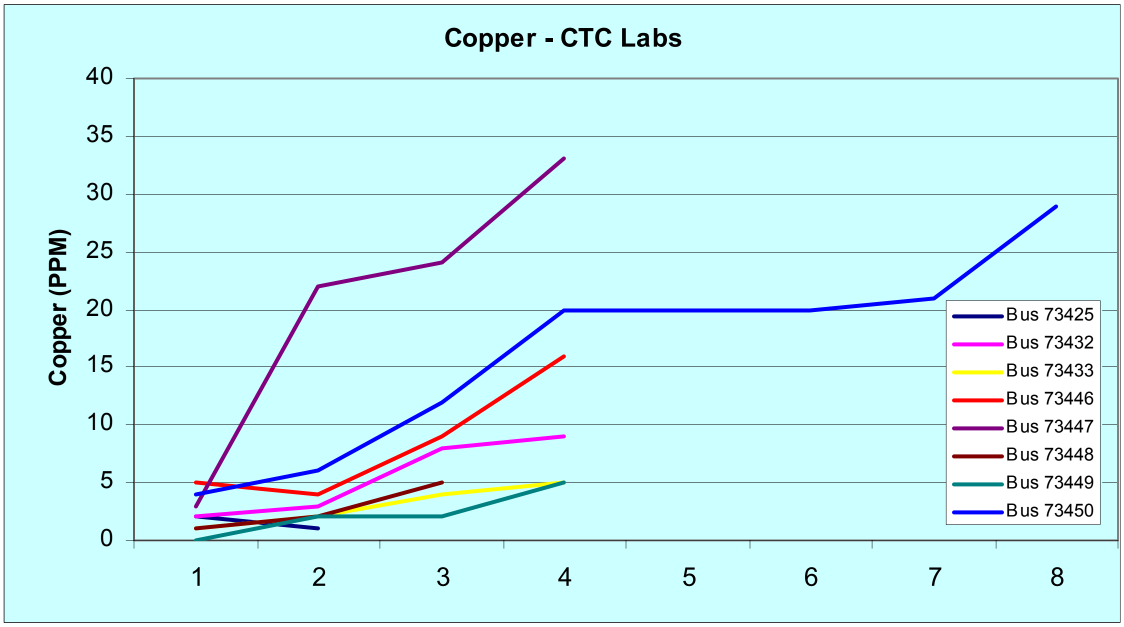

Figure 9. Copper sources include bushings, bearings, thrust-washers, friction plates, oil coolers and as an additives in oil. There is no definitive acceptable range for the presence of oil.

Table 3. Oil analysis report histories for three bus engine wear metals (iron, lead, and copper).[1]

Bus Number	Test Date	Miles on Oil	Iron (ppm) [2]	Lead (ppm)	Copper (ppm)	Iron Wear Rate Ratio[3]	Lead Wear Rate Ratio	Copper Wear Rate Ratio
73425	4/2/03	6,376	15	2	2	2.4	0.3	0.3
	6/3/03	12,919	33	3	1	2.6	0.2	0.8
73432	3/11/03	6,0921	24	4	2	3.9	0.7	0.3
	4/14/03	12,320	28	3	3	2.3	0.2	0.2
	8/11/03	24,935	60	9	8	2.4	0.4	0.3
	12/17/03	38,868	76	13	9	2.0	0.3	0.2
73433	2/12/03	6,700	30	4	1	4.5	0.6	0.1
	5/4/03	13,322	49	3	2	3.7	0.2	0.2
	7/29/03	25,617	124	10	4	4.8	0.6	0.2
	12/18/03	38,487	130	11	5	3.4	0.3	0.1
73446	1/15/03	9,949	11	2	5	1.1	0.2	0.5
	1/30/03	12,136	8	1	4	0.7	0.1	0.3
	4/30/03	22,648	18	5	9	0.8	0.2	0.4
	12/16/03	37,827	44	92	16	1.2	2.4	0.4
73447	3/11/03	5,908	9	3	3	1.5	0.3	0.3
	6/18/03	13,780	15	5	22	1.1	0.4	1.6
	7/21/03	17,164	15	5	24	0.9	0.3	1.4
	10/13/03	26,089	38	46	33	1.5	1.8	1.3
73449	2/4/03	6,168	5	1	0	0.8	0.2	0.0
	4/22/03	12,572	10	3	2	0.8	0.2	0.2
	9/11/03	24,771	15	14	5	0.6	0.6	0.2
73450	1/8/03	6,934	20	1	4	2.9	0.1	0.6
	1/21/03	14,545	50	1	6	3.4	0.1	0.4

Bus Number	Test Date	Miles on Oil	Iron (ppm) [2]	Lead (ppm)	Copper (ppm)	Iron Wear Rate Ratio[3]	Lead Wear Rate Ratio	Copper Wear Rate Ratio
	3/17/03	25,871	91	4	12	3.5	0.2	0.5
	6/16/03	43,031	206	11	20	4.8	0.3	0.5
	7/2/03	45,968	162	9	20	3.5	0.2	0.4
	7/23/03	54,812	183	11	20	3.3	0.2	0.4
	8/25/03	65,369	212	15	21	3.2	0.2	0.3
	10/6/03	68,821	425	18	29	6.2	0.3	0.4

1: Oil analysis reports from CTC laboratory of Phoenix, Arizona.

2: ppm = parts per million.

3: Wear Rate Ratio (ppm/k miles).

Bus Particulate Count Analysis

During this reporting quarter, particulate count samples were taken on the eight test buses, and on four other buses as control units for comparison. The eight test buses have four-cycle diesel-powered engines; two of the control buses were two-cycle diesel engines; the other two were liquid natural gas-powered engines. However, the test laboratory has not yet completed the test analysis for inclusion of the data into this report

LIGHT-DUTY VEHICLE TESTING ACTIVITIES

Light-Duty Vehicle Bypass Filter Installations

During this reporting quarter, six 2002 Chevrolet Tahoe vehicles were outfitted with puraDYN PFT-8 filter systems (8-quart capacity). Table 5 lists the vehicle number, bypass filter installation date, and vehicle and oil filter evaluation miles for the six Tahoes.

Table 5, Light-duty vehicle installation and mileage information for the six INEEL Tahoes with the oil bypass test systems installed.

Vehicle	Date Filter Installed	Vehicle Mileage at Installation	Vehicle Mileage at 1/1/04	Oil Filter Evaluation Miles
71326	12/10/03	45,812	47,156	1,344
71333	11/12/2003	40,825	44,128	3,303
71391	12/17/2003	34,910	36,416	1,506
71394	12/4/03	43,938	47,569	3,631
71400	11/24/2003	43,966	50,540	6,574
71402	12/4/2003	38,618	41,653	3,035
			Total Miles	19,393

The first system was installed on Tahoe 71333 on 11/12/03 and required approximately 8 hours to complete, whereas the last vehicle, 71391, required approximately 5 hours for installation. Due to the tight quarters in the engine compartment, the INEEL mechanic fabricated a special bracket to hold the filter housing (or canister) in the passenger-side engine compartment at the firewall (Figures 10 and 11). Installing the light-duty vehicle type of bypass filter, which requires gravity feed of the oil back into the oil pan, requires about 14 inches of gradient between the filter and the oil pan.

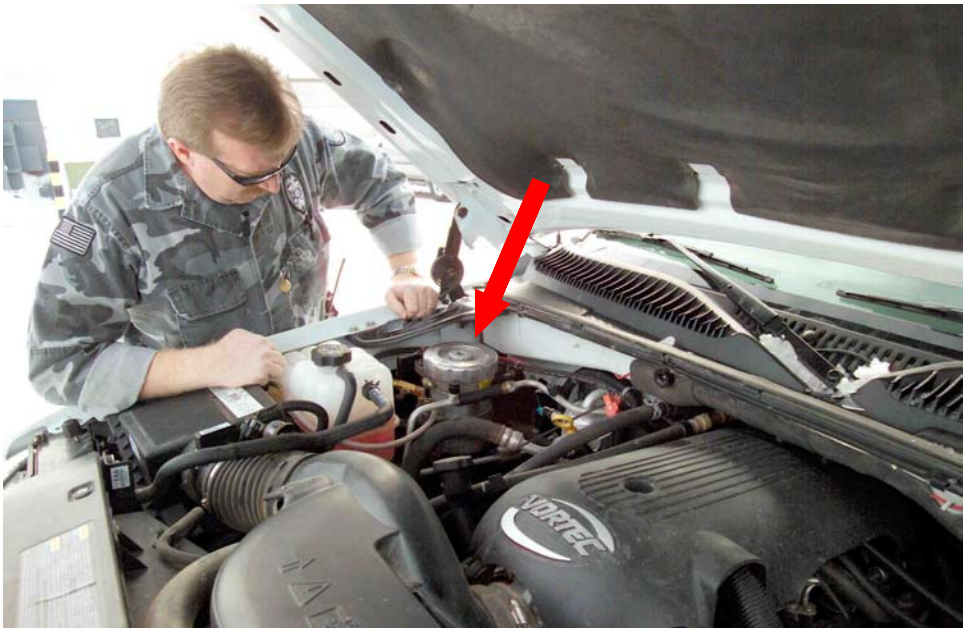

Figure 10. INEEL personnel viewing the location (red arrow) of the oil bypass filter installation in the engine compartment of an INEEL Chevrolet Tahoe.

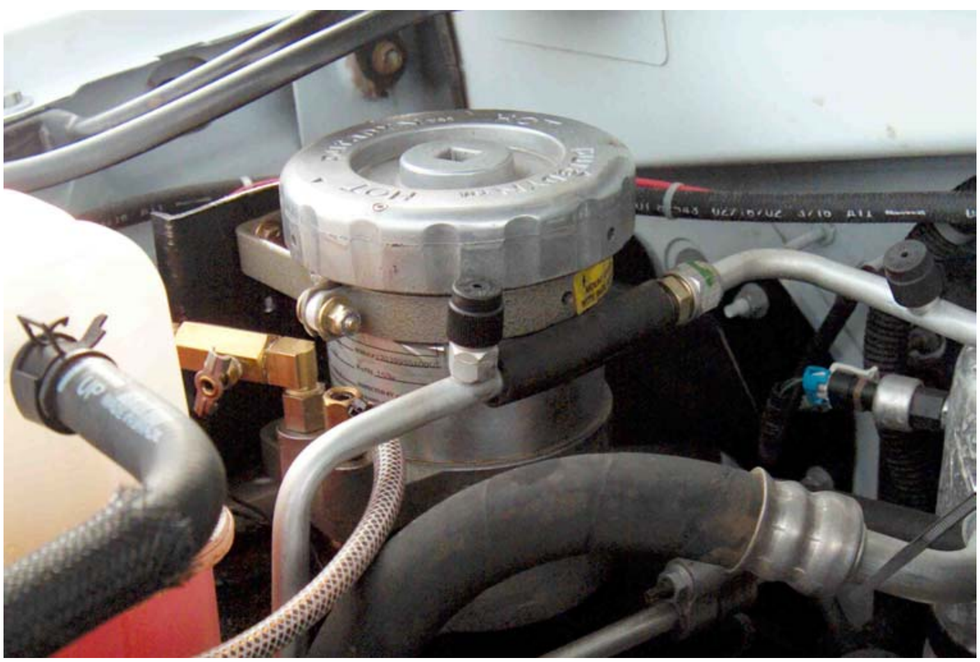

Figure 11. Close-up view of an oil bypass filter in a Chevrolet Tahoe engine compartment.

Light-duty Vehicle Filter Installation: Lessons Learned

Two lessons were learned during the light-duty vehicle bypass filter installation process.

Lesson 1. The Metering Jet

To supply oil to the filter system, a flexible oil line is used to tap into a source of oil pressure from the engine. A metering jet is placed in-line with the oil supply line to reduce the flow into the bypass filter system. Bypass filters are too dense for a high oil flow rate. The standard or normal metering jet has a 1/32-inch-diameter orifice that flows about six gallons of oil per hour into the filter. The standard jet operational pressure is limited to 65 pounds per square inch (psi) oil pressure, or less. The mechanic ran the engine after installation to check for leaks and none were found. It was thought that this metering jet was properly matched to the Tahoe engine pressure, however, the vehicle was returned to the mechanic a couple of days later with oil leaking out of the vent hose on the filter housing. It was discovered that oil pressure is significantly higher when the vehicle is started after sitting out in sub-freezing temperatures over night. When the vehicle was started in the morning, the cold oil had too much backpressure, and the standard-size orifice allowed too much flow, therefore oil over-flowed out of the vent hose. The mechanic referred to the installation manual, which suggests that with higher oil pressures (>65 psi), the high-pressure jet, with a 1/64-inch orifice diameter, should be used. The standard metering jet was replaced, and the high-pressure jet was used for the remaining installations. This reduced the flow rate to the filter (about four gallons per hour), and no subsequent overflows occurred. Therefore, for cold climates, use a high-pressure metering jet.

Lesson 2. Oil Changes and the Installation Process

The second lesson learned from the installation is to install the system hardware first and then connect the hoses to the oil pan when the oil is changed, but before adding new oil. If the oil is changed first, before the filter installation, then the new oil has to be dropped in order to install the oil return line to the oil pan drain plug opening. This occurred only on the first light-duty vehicle installation.

Light-duty Vehicle Filter Evaluation Status

Many oil analysis samples were taken throughout the year on the Tahoes to establish a baseline on the engine wear metals before the oil bypass filters were installed. As stated in earlier reports, the Tahoe engines tend to generate a higher copper wear metal in the oil. In ten oil analysis reports, the copper averaged 95 ppm. The copper values ranged between 10 to 242 ppm. The high copper levels appear to be common to this engine. At this date, minimal oil analysis data are available on these engines, since the filters were installed in November and December. The next quarterly report will include light-duty vehicle oil bypass filter test data.

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 324,091 miles. With a 12,000-mile servicing schedule, this represents an avoidance of 27 oil changes, which equates to 952 quarts (238 gallons) of new oil conserved and 952 quarts of waste oil not generated.

Oxidation and nitration analysis have been added to the suite of oil analysis test to measure fitness of the oil, and data are being collected, but limited data are available at this time.

The light-duty vehicle bypass oil filter systems were installed on six Chevrolet Tahoe vehicles and oil analysis data are being collected. To date, the six vehicles have accumulated 19,393 miles. With a 3,000-

mile service schedule, this represents an avoidance of six oil changes, which equates to 36 quarts (9 gallons) of new oil conserved and 36 quarts of waste oil not generated.

Oil quality values of TBN, soot, and viscosity from all of the CTC Laboratory oil analysis reports received to date were graphed. The graphed results show that oil quality is degrading for TBN and soot, but all of the bus oils are still within safe operating limits. The graphed results for viscosity are relatively flat or consistent and show no negative trends.

Three wear metals—iron, lead, and copper—from all of the CTC Laboratory oil analysis reports received were showing increasing concentrations. The values of the three metals were also plotted. However, this increasing trend is expected, since the metals are accumulating at what appear to be a pace normal to extended oil use. Because of the extended oil use, the graphs can be somewhat misleading when viewed conventionally—using condemnation values based on oil that is discarded with each servicing. With extended drain intervals, metals can safely continue to accumulate while the analysis results suggest higher levels of accumulated contaminants.

Twenty-nine wear rate ratio (ppm of metal/1,000 miles) analyses for three wear metals (iron, lead, and copper) were calculated and the majority are relatively consistent. There were three ratios that significantly increased over the previous oil analysis report—lead in buses 73446 and 73447 and iron in bus 73450. The next quarterly report will reexamine these ratios to ascertain whether a negative trend is continuing.