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External Police Fleet Tests

As part of any fluid development program, the continuous stress testing of potential product candidates in question is highly important. Typically, after exhaustive laboratory testing follows a need to determine how the best engine coolant candidates will behave in actual vehicles, versus products currently in commercial use. This can be approached in many ways. One is to test the candidate fluids under more stressful conditions than the fluids would be put under by normal operating conditions. An ideal fleet to accomplish this stress testing in are police vehicles. Police operations will put the coolant and coolant system through much harsher conditions where the vehicle will often run under extended idle conditions and quick, high rpm operations. Once the coolant performance is understood under these conditions then more controlled internal fleets can be tested to further differentiate the performance of the product.

The test data presented here was obtained from operating two different vehicle fleets, Ford Crown Victorias (2007-2011) and General Motors Chevrolet Caprices (2013).

- The Ford Crown Victorias are 4.6 L, 8 cylinder police vehicles located in the state of New York. Prestone Cor-Guard, a commercial aftermarket Extended Life Organic Acid (OAT) and Ford Factory Fill coolant were tested.
- The GM Chevrolet Caprices are 6.0 L, 8 cylinder police vehicles located in the state of New York. The Prestone Cor-Guard and GM Factory Fill coolant were tested.

Ford Crown Victoria Fleet

The commercial OAT Extended Life and Ford Factory Fill coolants were installed in the police car cooling system as soon as practical for the fleet test after the new vehicle arrived at the police station. All test vehicles were handled the same. The cooling system was drained, flushed with tap water, drained and filled with test coolant concentrate. The test coolant used was diluted to

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50 vol. % with police station tap water. The same flushing procedure was used so that all vehicles were handled in the same fashion regardless of coolant being put on test. Startup mileage in the fleet tests ranged from 0 miles to 1,500 miles. Hour meters were utilized in all of the vehicles to track operating time. Startup mileage for the Prestone Cor-Guard vehicles in the fleet test ranged from 51,000 to 89,000 miles. New water pumps were installed and the same flushing procedure used so that all vehicles were handled in the same fashion regardless of coolant being put on test. The test vehicles were maintained according to standard operating procedures. The concentration of the test coolant in the test vehicles was monitored by measuring the refractive index and adjusted, if necessary, to 50 vol. % by adding either tap water or test coolant concentrate.

Fleet Test Results

Coolant chemistry

Many stresses are put on the coolant over the duration of use in vehicle cooling systems. These stresses including: operating temperature, cooling system design, operating/driving conditions, cooling system metallurgy, and engine load to name a few. How the coolant reacts to these stresses is determined by the quality of glycol and the choice and blending of the inhibitor package chemistry. One useful gauge to determine how well the inhibitor chemistry is working to protect the cooling system is to measure the rate of glycol degradation in the coolant. The ethylene glycol in engine coolants can generate acidic degradation products, such as glycolic acid and formic acid [1-4]. The production of these acidic glycol degradation products will gradually reduce the pH of the engine coolant and can eventually led to a substantial increase of metal corrosion rates in the engine cooling system. Hence, monitoring the level of these acids is useful in determining the durability and the service life of the engine coolant [5, 4]. Figure 1

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shows the total glycol degradation acid concentration (i.e., sum of glycolic acid, formic acid and acetate to acid concentration in the coolant) as a function of test mileage for the three coolants.

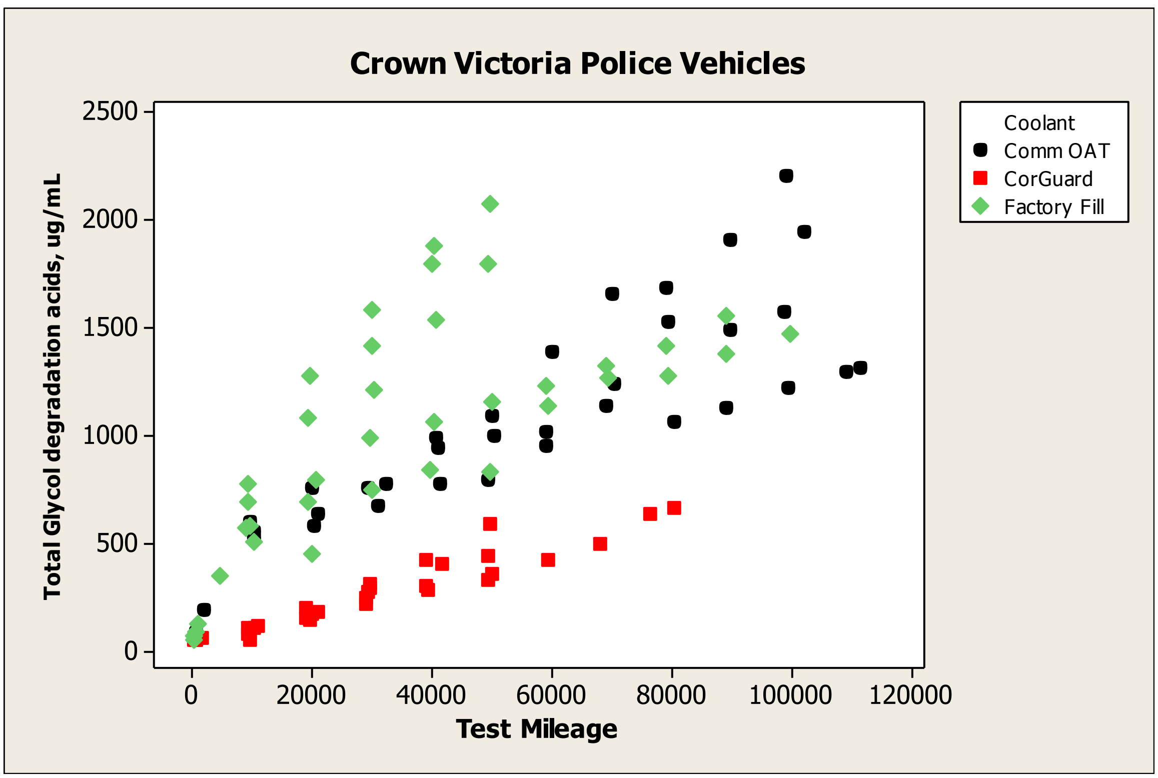

Figure 1. Total glycol degradation acid concentration as a function test mileage – Commercial OAT, Prestone Cor-Guard and Ford Factory Fill coolants.

If all three coolant chemistries where equivalent, it would be expected that the glycol degradation rate would be the same. In fact, the Ford Factory Fill and Commercial OAT

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coolants have a higher glycol degradation rate, even though they were added to clean, non-corroded cooling system metals. Therefore, one would also expect, that the Prestone Cor-Guard coolant would show the highest rate of glycol degradation because after a flush it was put into higher mileage vehicles with a pre-corroded cooling system. However, the total glycol degradation acid concentrations generated by the Prestone Cor-Guard coolant is roughly ⅓ to ¼ of the amount generated by the Commercial OAT and Ford Factory Fill coolants under comparable test mileage conditions.

To help to prevent corrosion of the metal components in the engine cooling systems and to extend the life of the coolant, it is critical to maintain the coolant pH at the optimal levels throughout its useful life. Excessive change of coolant pH during vehicle use can negatively impact the corrosion protection performance of the coolant and in some cases can result in instability of the coolant formulation, leading to precipitate formation in the cooling systems that could potentially restrict flow and cause loss of heat transfer efficiency.

Figure 2 shows the fleet test coolant pH as a function of test mileage for the Commercial OAT, Prestone Cor-Guard and Ford Factory Fill coolants. After an initial drop of ~0.4 pH units for the Commercial OAT and Ford Factory Fill coolants, all three coolants show a stable pH over the duration of the test consistent with the Extended Life behavior expected from these coolants.

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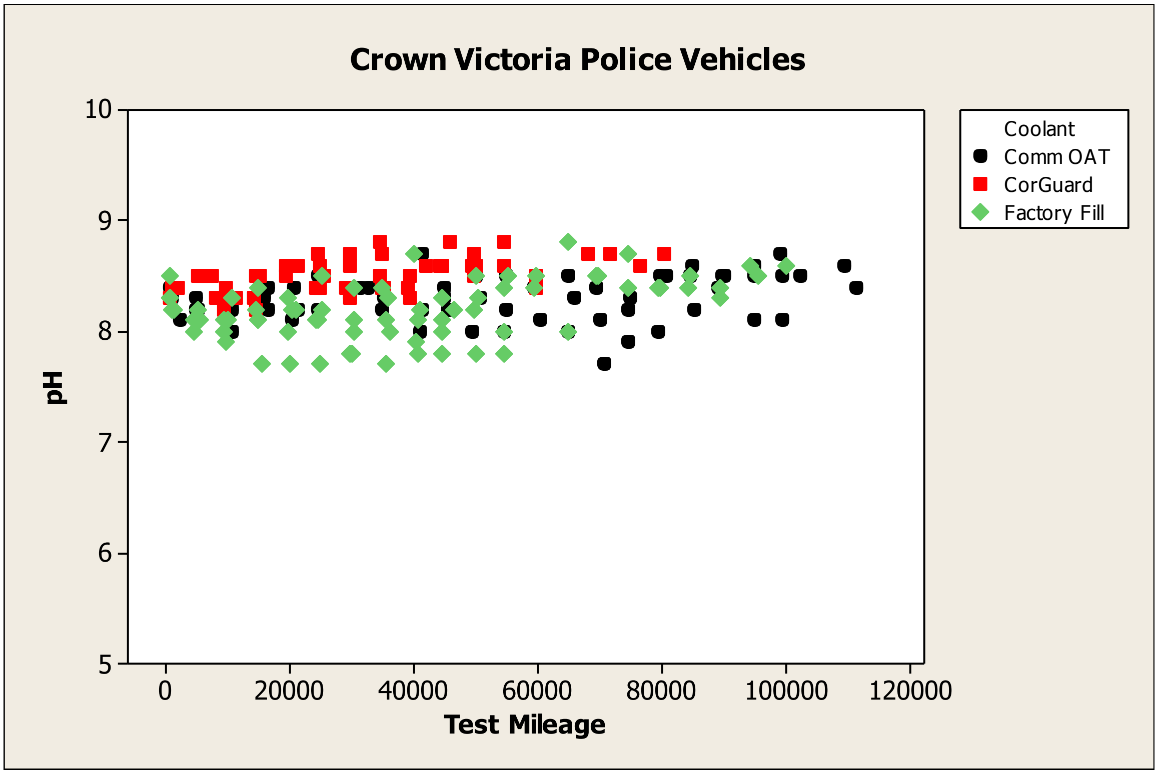

Figure 2. Test Coolant pH vs. test mileage for – Commercial OAT, Prestone Cor-Guard and Ford Factory Fill coolants.

A stable pH; however, is not enough to guarantee extended life protection of the cooling system. For true extended life protection the inhibitor technology used must be both effective and stable over the lifetime of the product. Looking at the key inhibitors in these coolants we first see that the organic acids levels for all three coolant remain stable throughout the test, Figure 3.

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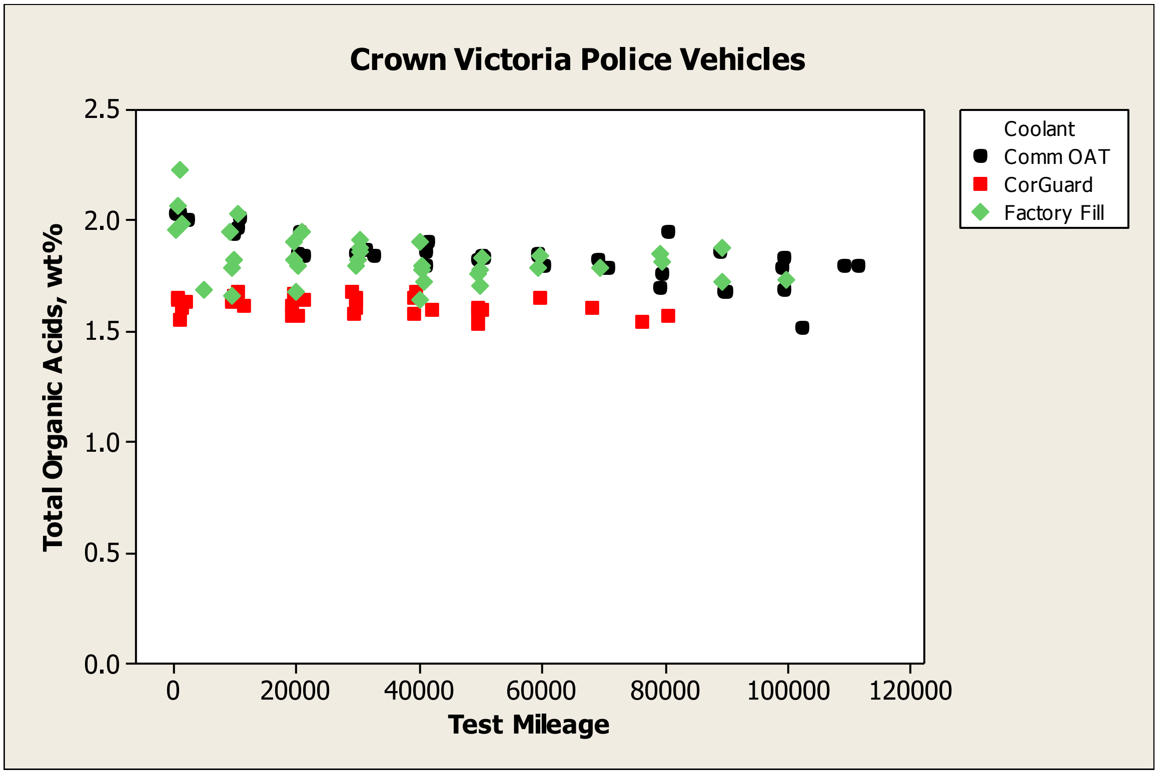

Figure 3. Total Organic Acid levels vs. test mileage for – Commercial OAT, Prestone Cor-Guard and Ford Factory Fill coolants.

This trend does not hold true for a key second inhibitor. One can see from comparing the results in Figure 4, among the three coolants tested, the azole concentration depleted the fastest in the Commercial OAT and Ford Factory Fill coolants, dropping to ~50% after 80,000 miles. The azole concentration in the Prestone Cor-Guard also decreased but at a slower rate, dropping to ~70% after 80,000 miles. In addition, another key corrosion inhibitor in the Prestone Cor-Guard, not present in the other two test coolants, was tracked as a function of test mileage, Figure 5. The data shows the inhibitor concentration is stable as a function of test miles.

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It should be noted that the azole concentration depletion results obtained in the fleet test of the current study for OAT coolants were in general agreement with the results reported earlier by other researchers for different OAT coolants using different test vehicles [6-9].

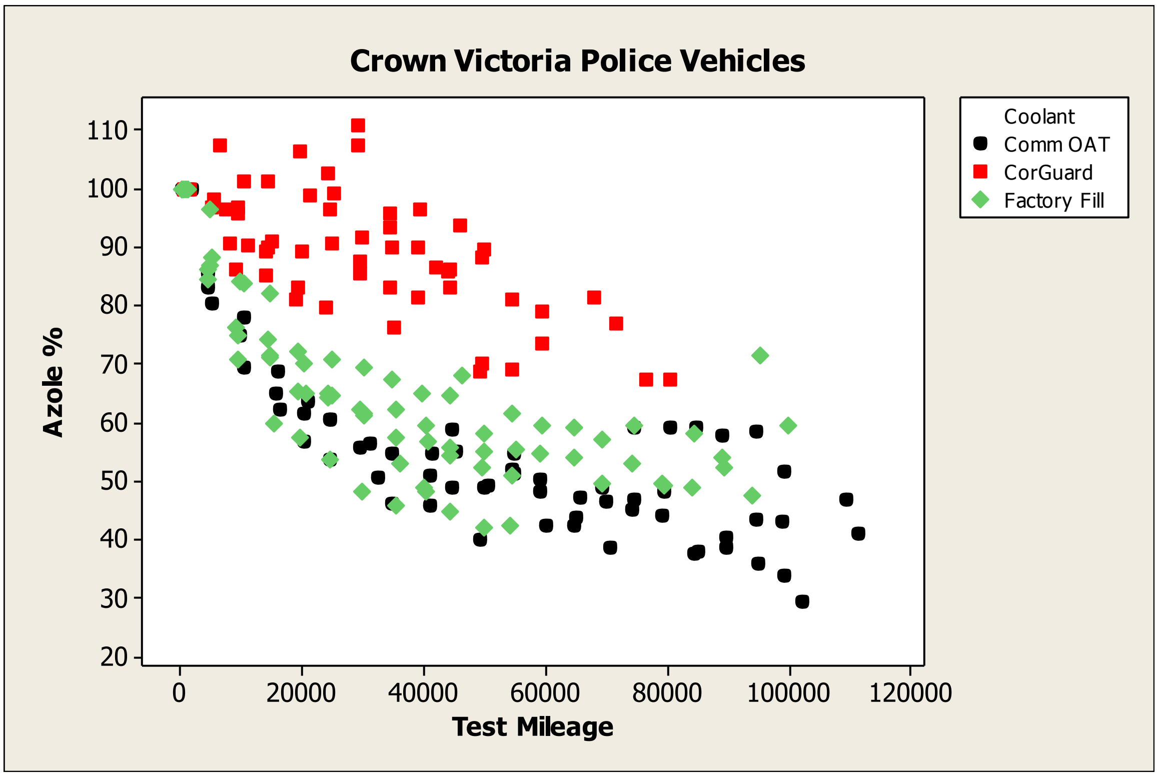

Figure 4. Azole % levels vs. test mileage for – Commercial OAT, Prestone Cor-Guard and Ford Factory Fill coolants.

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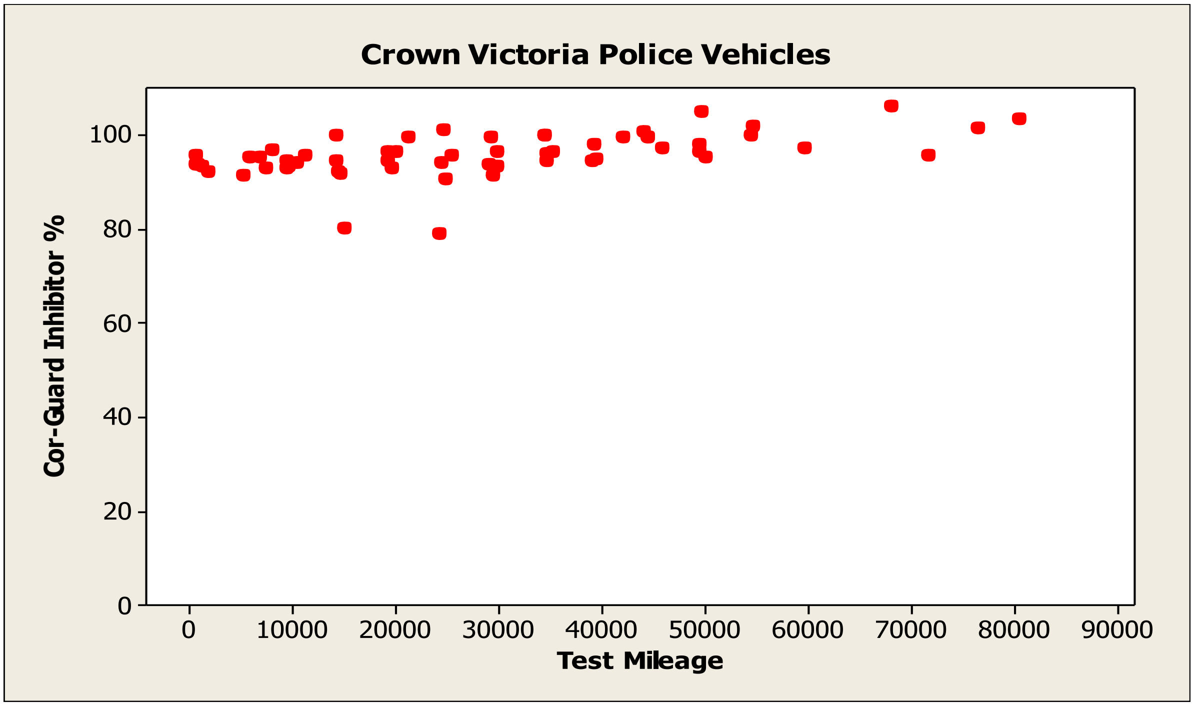

Figure 5. A key Cor-Guard Inhibitor % levels vs. test mileage for – Prestone Cor-Guard coolant.

Corrosion Protection:

During the fleet testing, there was the opportunity to remove the cooling system water pump from three vehicles for inspection. The first came from a vehicle that ran for 97,085 miles on Ford Factory Fill coolant, Figure 6a. The surface of the pump is showing signs of general surface corrosion as well as localized cavitation damage. The other water pumps removed came from two vehicles that had a new water pump installed and flushed-n-filled with Prestone Cor-Guard. These pumps were removed at 57,035 and 99,916 test miles for inspection, Figure 6 b and c. Both pumps show no sign of general surface corrosion or cavitation damage, in fact the pump surfaces look like fresh metal. The appearance of the pumps demonstrates both the fast acting and extended life corrosion protection provided by Prestone Cor-Guard.

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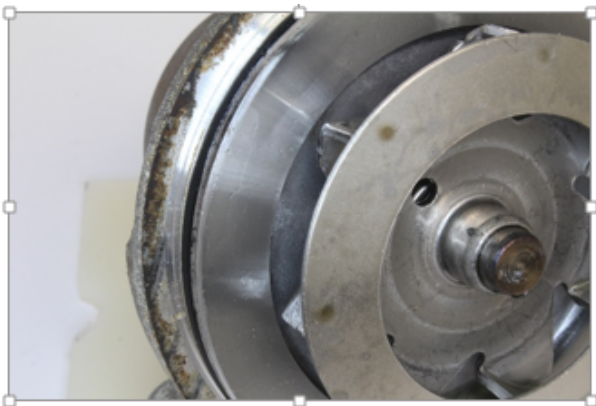
a) Factory Fill Coolant at 97,085 test miles



b) Prestone Cor-Guard at 57,035 test miles

c) Prestone Cor-Gard at 99,916 test miles

Figure 6. Cooling System Water Pump removed from Police fleet vehicles a) 1752-1-97K b) 4448-2-119K c) 4450-2-157K

These results are consistent with laboratory testing of the Prestone Cor-Guard versus standard commercial aftermarket OAT Extended Life coolants. In a laboratory test, a set of 12 closely matched pumps as specified in ASTM D2809 were selected for use in testing.   The test involved two coolants, Prestone Cor-Guard and a commercial Extended Life OAT product of known performance. Six of the pumps were randomly selected and sent to an outside independent laboratory to conduct the testing, following the ASTM D2809 procedure. The other 6 pumps were used for internal testing following the ASTM D2809 procedure but in a modified stainless

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steel unit. At the end of testing, all 12 pumps were measured and rated by the outside independent laboratory for consistency.

The results of the ratings are given in Table 1. In Figure 7 and 8 are representative pictures of the pumps at the end of the ASTM D2809 test. Discoloration was observed in the older pump design due to carryover from residual on the copper piping in the unit, Figure 7. This carryover is not seen in the stainless steel unit, Figure 8. The results from Table 1 shows the Prestone Cor-Guard provides better cavitation corrosion and erosion corrosion protection to the water pump in both test units when tested, similar to what was seen in the fleet vehicles.

Table 1: Summary of Water Pump Test Results using the rating system in ASTM D2809.

Test Fluid	Testing Lab	Pump Rating	Test
Commercial OAT	Independent Lab	5	Current ASTM test
Commercial OAT	Independent Lab	7	Current ASTM test
Commercial OAT	Independent Lab	8	Current ASTM test
Commercial OAT	Internal Testing	8	Modified Test
Commercial OAT	Internal Testing	8	Modified Test
Commercial OAT	Internal Testing	8	Modified Test
Prestone Cor-Guard	Independent Lab	9	Current ASTM test
Prestone Cor-Guard	Independent Lab	8	Current ASTM test
Prestone Cor-Guard	Independent Lab	9	Current ASTM test
Prestone Cor-Guard	Internal Testing	10	Modified Test
Prestone Cor-Guard	Internal Testing	10	Modified Test
Prestone Cor-Guard	Internal Testing	10	Modified Test

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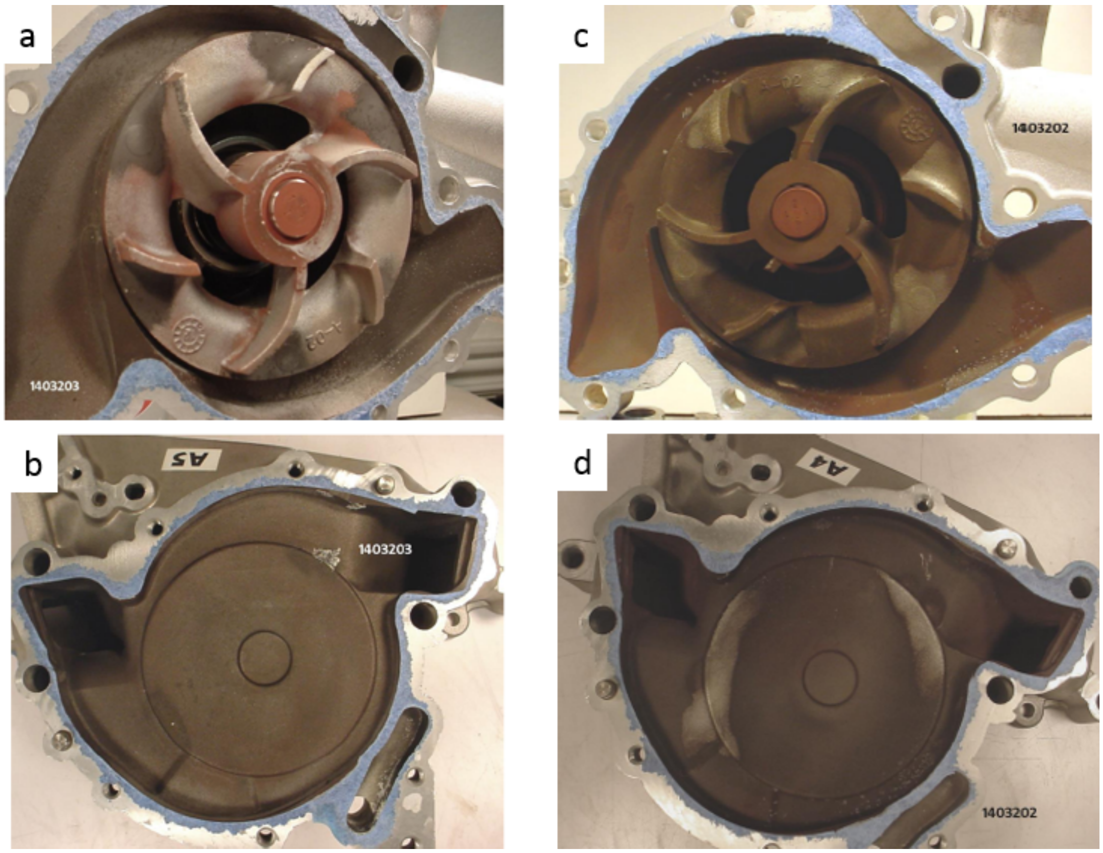

Figure 7. ASTM D2809 pump test result by outside independent laboratory a) pump and b) pump cover for Prestone Cor-Guard; c) pump d) pump cover for the Commercial Extended Life OAT coolant.

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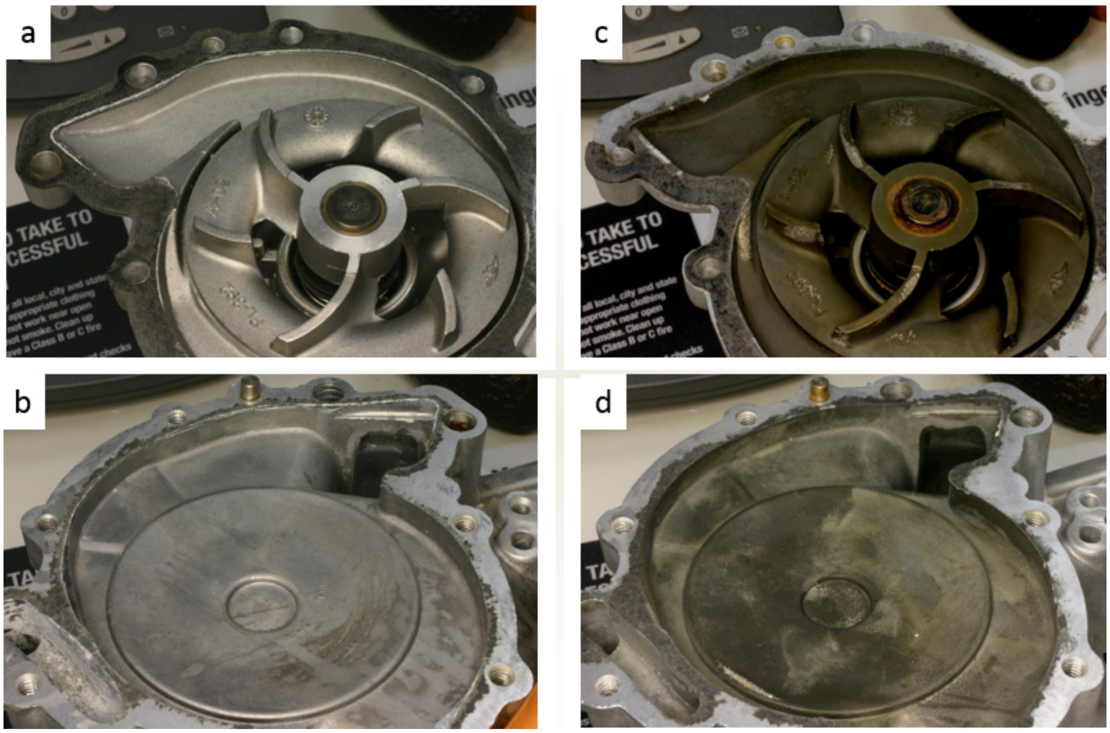

Figure 8. ASTM D2809 pump test result in stainless steel unit by internal laboratory a) pump and b) pump cover for Prestone Cor-Guard; c) pump d) pump cover for the Commercial Extended Life OAT coolant

General Motors Caprice Fleet

The Prestone Cor-Guard and General Motors (GM) Factory Fill coolants were installed in the police car cooling system as soon as practical for the fleet test after the new vehicles arrived at the police station. The cooling system was drained, flushed with tap water, drained, and filled with test coolant concentrate. The test coolant was diluted to 50 vol. % with police station tap water. The same flushing procedure was used on all vehicles regardless of coolant being put on test. Startup mileage in the fleet tests ranged from 0 miles to 1,100 miles. Hour meters were utilized in all of the vehicles to track operating time.   The test vehicles were maintained according to standard operating procedures. The concentration of the test coolant in the test vehicle was monitored by measuring the refractive index and adjusted, if necessary, to 50 vol. % by adding either tap water or test coolant concentrate.

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Fleet Test Results

<u>Coolant chemistry</u>

As was seen in the Crown Victoria fleet, the total glycol degradation acid concentration (i.e., sum of glycolic acid, formic acid and acetate to acid concentration in the coolant) as a function of test mileage was much higher for the GM Factory Fill coolant versus Prestone Cor-Guard. In this case, where both coolants have been added to the relatively new cooling system, the GM Factory Fill coolant total glycol degradation levels are ~800 µg/mL higher than for Prestone Cor-Guard at 70,000 test miles (~1100 µg/mL to ~300 µg/mL, respectively), Figure 9.

Figure 10 shows the fleet test coolant pH as a function of test mileage for Prestone Cor-Guard and GM Factory Fill coolants. The Cor-Guard coolant did not show an initial pH drop and maintained a stable pH over the course of the test. After an initial drop of ~0.6 pH units for the GM Factory Fill coolant, it showed a stable pH over the duration of the test. These results are consistent with what was seen the Ford Crown Victoria fleet testing and what would be expected from these extended life coolants.

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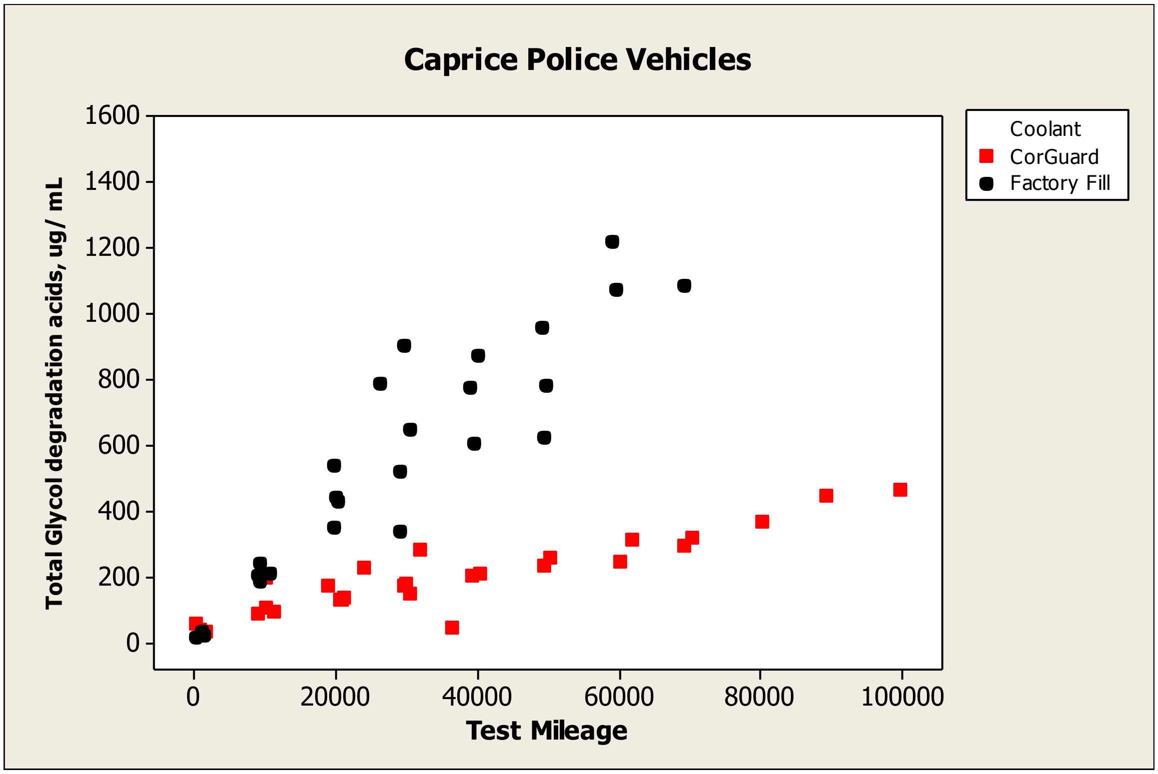

Figure 9. Total glycol degradation acid concentration as a function test mileage –Prestone Cor-Guard and GM Factory Fill coolants.

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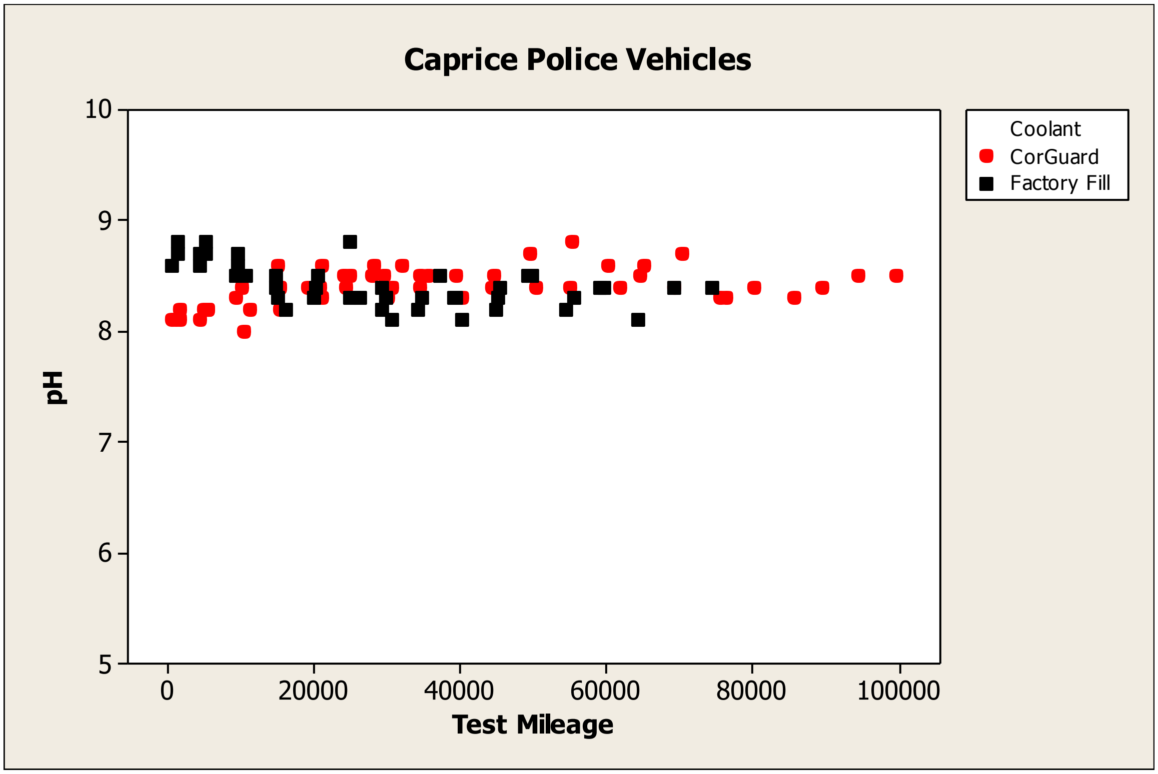

Figure 10. pH level as a function test mileage –Prestone Cor-Guard and GM Factory Fill coolants.

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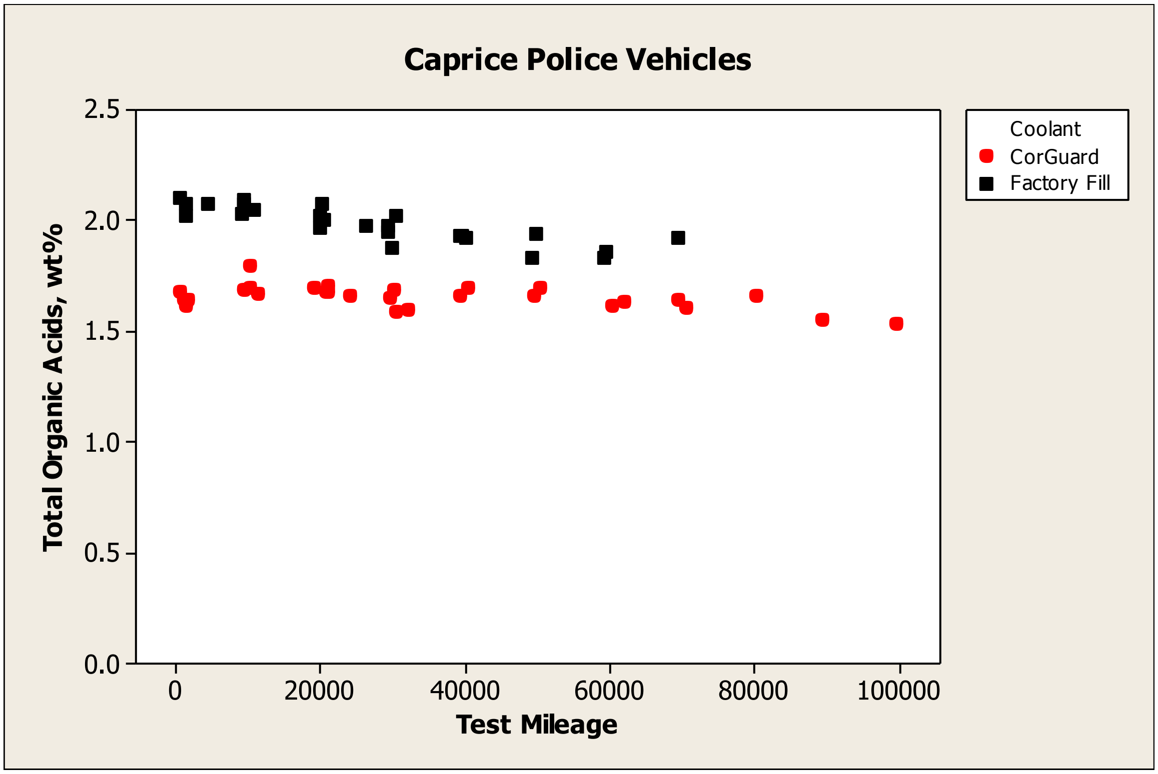

Figure 11. Total Organic Acid level as a function test mileage – Prestone Cor-Guard and GM Factory Fill coolants.

As with the Crown Victoria fleet, the total organic acid inhibitors in both coolants remained stable throughout the test, Figure 11.

As seen in the Crown Victoria fleet, the total Azole % depletes significantly faster in the GM Factory Fill coolant as compared to the Prestone Cor-Guard, Figure 12.   At ~70,000 test miles, the factory fill Azole % is approaching ~ 40% while the Prestone Cor-Guard azole% is at ~80%.

Looking at the other key corrosion inhibitor in Prestone Cor-Guard, not present in the GM Factory Fill coolant, the data shows that after an initial drop, the inhibitor % levels out and remains stable as a function of test mileage for Prestone Cor-Guard, Figure 13.

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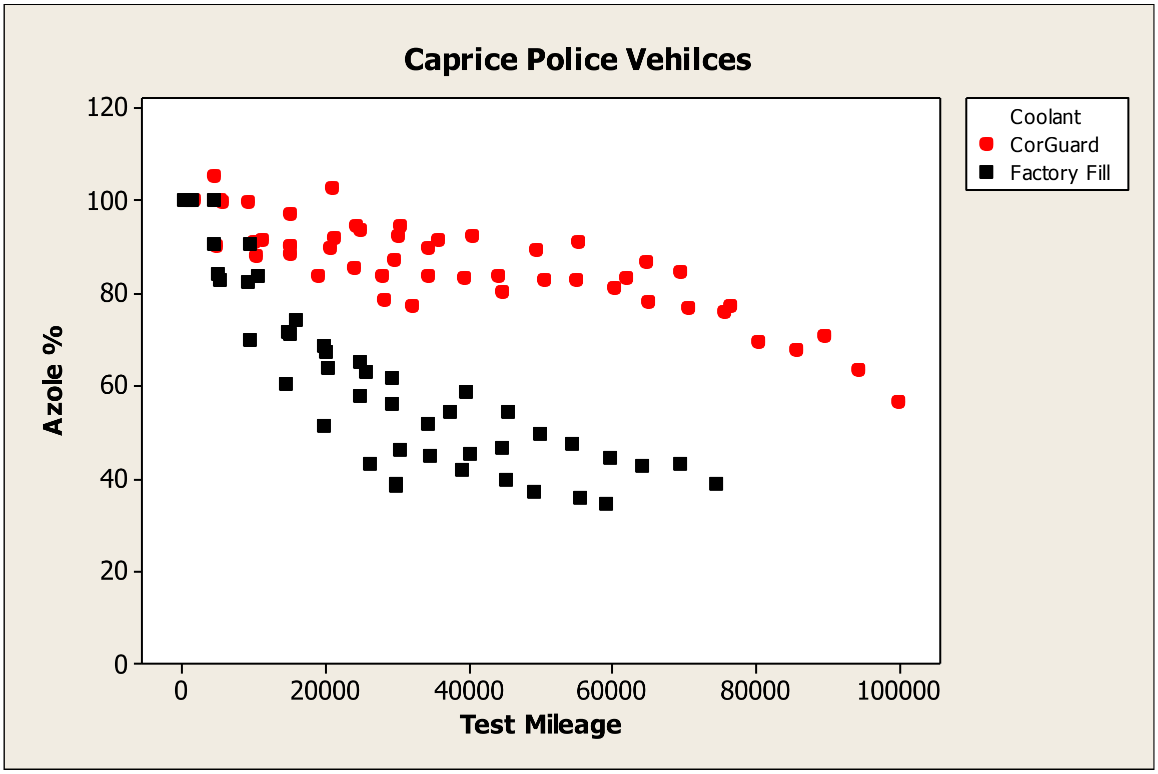

Figure 12. Total Azole, % as a function test mileage – Prestone Cor-Guard and GM Factory Fill coolants.

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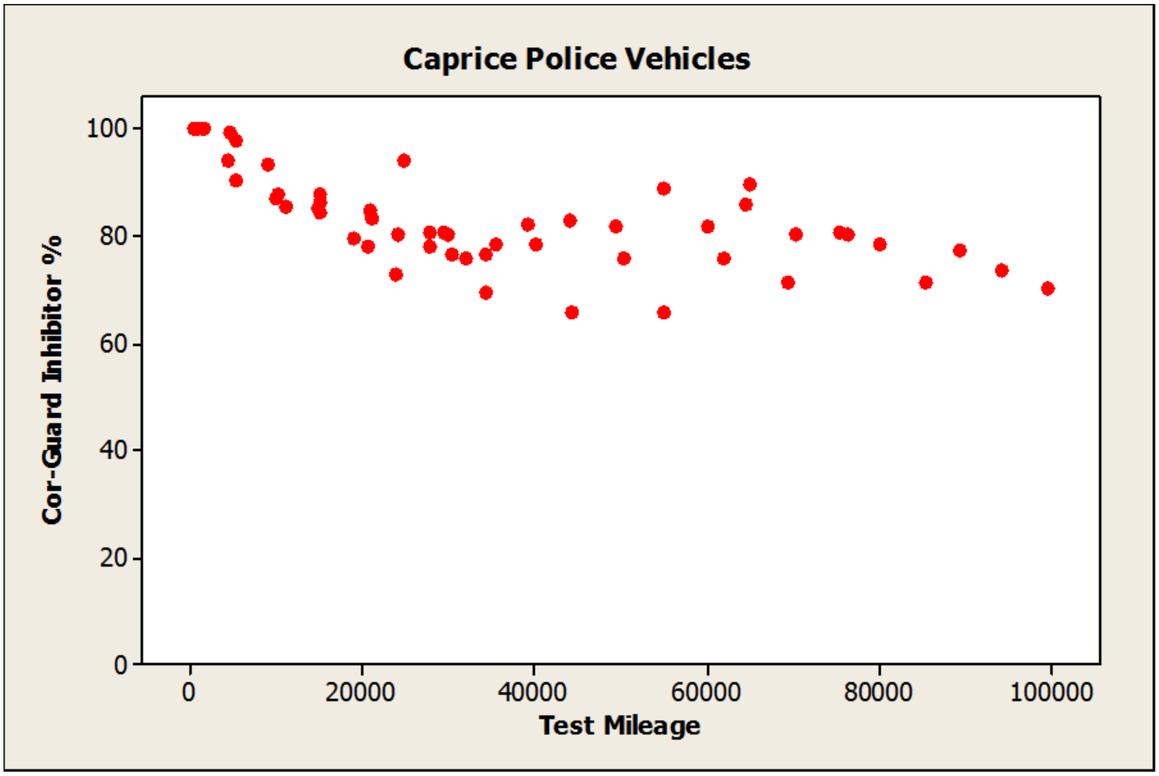

Figure 13. A key Cor-Guard Inhibitor % levels vs. test mileage for – Prestone Cor-Guard coolant.

Conclusions of External Police Fleet Tests

The Prestone Cor-Guard was stress tested in two vehicle platforms under two different set of conditions: a) flush-n-fill into vehicles' cooling systems after 51 to 89K vehicle miles and b) flush-n-fill in new police vehicles with low mileage. In both cases, the Prestone Cor-Guard showed improved performance over the standard reference Extended Life Organic Acid (OAT) coolant(s). The Prestone Cor-Guard performance exhibited:

- Fast protection to the aluminum cooling system components
- Protection against ethylene glycol degradation
- Stable pH throughout the vehicle operations
- Improved inhibitor package stability

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- Improved protection to the water pump against cavitation and general surface corrosion.

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