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November 1st, 2016

Internal Ford Fusion Fleet Test

As part of the development work for the Prestone Cor-Guard Extended Life formulation which uses OAT technology, the service life of the new formulation needed to be determined. A series of outside police vehicles have been run on the Cor-Guard OAT technology to determine an initial baseline for this product. The technology has shown itself to provide excellent performance under the harsh police driving conditions/ environment in various vehicle types. As a result, it was determined that this technology should be further tested under a more controlled test environment versus a known reference fluid.

After reviewing the various ASTM, Industry and OEM standards for Extended Life Coolant fleet testing, was decided to narrow down potential fleet testing protocols to three potential candidates in the following specifications: Ford Motors WSSM97B44-E1 (dated February 6, 2012; later replaced by Ford WWS-M97B44-D); Chrysler MS-9769 (issued September 11, 2000) and General Motors GMW3420 (as of March 19, 2012, released July 2012).

It was decided that the best fleet test protocol option to follow to evaluate the useful life (service time) of the coolant was the Ford protocol.   There are several key differences between the recommended fleet test protocols we followed, versus the current Ford protocol. At the time the test started, this Ford test required testing to 50,000 miles for a 5 year or 106,000 mile coolant. This protocol has now been updated for a coolant with a 6 year/ 107,000 mile service life. The recommended test duration is for 150,000 mile test with an initial 80,000 mile check point. The 80,000 mile check point alone would correspond to an 8 year or 168,000 mile coolant life. Testing to the longer time and higher mileage was chosen to ensure a 5 year or 150,000 mile or higher requirement would be achieved. In addition, it was decided to use a current Factory Fill Extended Life OAT coolant that has been tested, approved and shown to meet GM's 5 year or 150,000 mile requirement as the reference fluid.   A summary of the test conditions/ protocols is given in Table 1.

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Table 1. Fleet Testing to Ford Motor Company Global Coolant Specifications, WSSM97B44-E1 (Feb 6, 2012)

Internal Control Fleet

- This test is being run as a comparison test (Prestone Cor-Guard vs. current Factory Fill 5/ 150 coolant)
- A 15 vehicle fleet – 8 Prestone Cor-Guard vs. 7 Factory Fill Coolant
- Test requires a minimum of 5 vehicles from each group will complete test
- Fleet will run at minimum 150,000 miles with an 80,000 miles check point (mileage accumulation not to exceed Ford standard, 50K/year)
- Test fluids will be monitored per Ford requirements
- End of Test Component examination: minimally Radiators, Heater Cores and Water Pumps will be examined at end of test

For the choice of vehicle was desired to run the test in a high volume, mid-size vehicle that has been sold for more than two years to ensure it was a representative vehicle in consumer hands. The vehicle selected was the Ford Fusion 2.5L.

Vehicle Selection – Ford Fusion 2.5 L

- Mid-Size Car Award 2011/2012
- Sixth best-selling car in 2011 [1]
- Ninth best-selling car in 2010 [2]

According to test protocol, all of the vehicles underwent a flush-n-fill procedure followed by the addition of the coolant to be evaluated. One of the 15 test vehicles was put on test prior to a matched 7 to 7 fleet test (Prestone Cor-Guard versus Factory Fill coolant) to ensure there were no problems with the flush-n-fill procedure. This lead vehicle was filled with Prestone Cor-Guard and ran 20,000 miles prior to the start of the other vehicles. The test vehicles' mileage accumulation has been 400 to 800 miles during the week with an average of 615 miles. The mileage is balanced between cars to ensure that they run between 30,000 to 34,000 miles per year, with a target of 32,000 miles. Hour meters were installed in the vehicles to track the

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operating time of the vehicles. During the week the test vehicles are run in the morning and afternoon cycles. This allows approximately three thermal cycles per day during the week. On the weekend, the vehicles may be used for short highway trips. The fluids are scheduled to be run at 50% +/- 2% concentration (by volume) with Danbury tap water. All of the vehicles are scheduled to have 60 ml samples taken at 500 test miles (+/- 100) and then every increment of 5000 (+/- 500) test miles. The samples are analyzed for specific physical properties and level of corrosion inhibitors as well as accumulation of glycol degradation products.

The useful life of any coolant is largely determined by the makeup of the inhibitor package and the depletion rates of the coolant's inhibitors. During use of the vehicle with ethylene glycol based coolants, the ethylene glycol and other glycols in the engine coolants can generate acidic degradation products, such as glycolic acid, formic acid and acetic acid. The generation of acidic glycol degradation products will gradually reduce the pH of the engine coolant and can eventually lead to a substantial increase of metal corrosion rates in the engine cooling system. Hence, monitoring the level of these acids is critical in determining the durability and the service life of the engine coolant. Figure 1 shows the total glycol degradation acid concentration (i.e., sum of glycolic acid, formic acid and acetate acid concentration in the coolant) as a function of test mileage for the 2012 Ford Fusion using the Extended Life Cor-Guard (blue) and the OAT Factory Fill fluid formulation (red). The Cor-Guard coolant formulation generated over 5.86 times less degradation products vs Factory Fill coolant.

Fig 1. Total Glycol Degradation Acid Concentration vs. test mileage: ▲= Factory Fill,
● = Prestone Cor-Guard.

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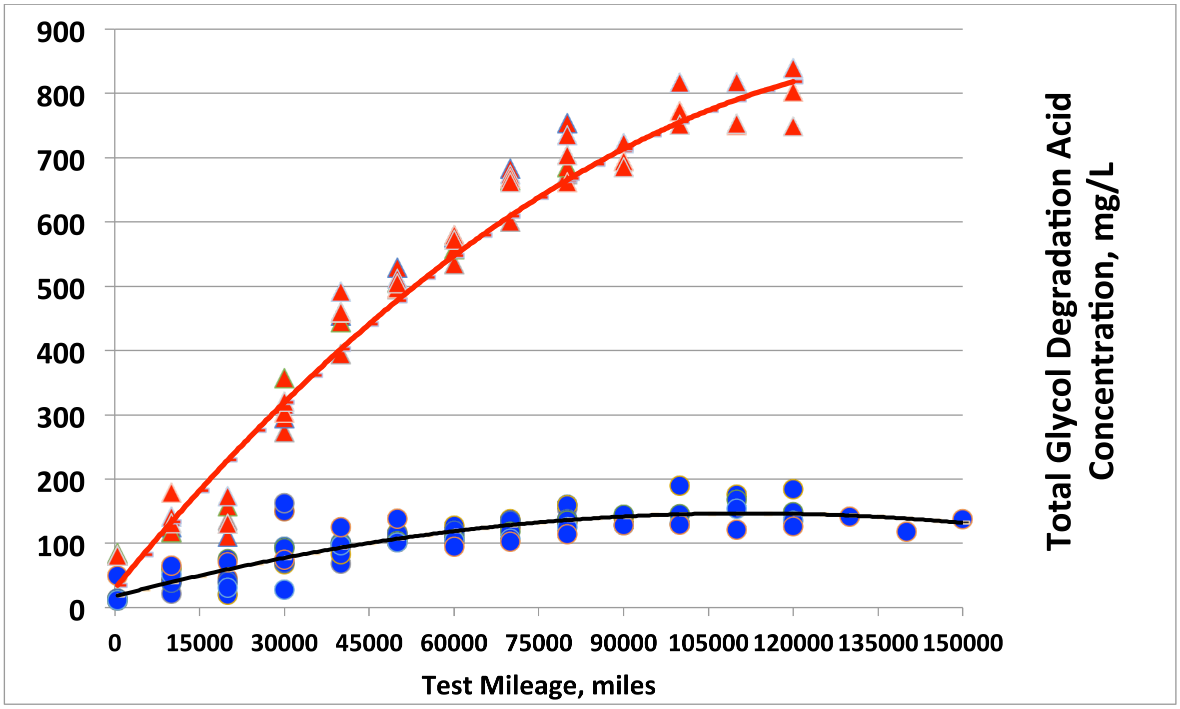

Traditional inhibitors are believed to protect against corrosion by the formation of a thin inhibitor layer on cooling system metal surfaces and establishing equilibrium in solution.[i] Analyses of the two coolants from these fleets show that the concentration of the carboxylic acids is relatively unchanged even to very high mileages. For example, data generated during the fleet operation show the organic and inorganic acids and other important corrosion inhibitors are still within 90-99% of its original concentration after 80,000 miles. Depletion rates of both carboxylic acids compare very favorably to silicate inhibitors, which show substantial depletion from solution within the first 20,000 to 25,000 miles of usage. For tolyltriazole, depletion occurs at a higher rate than observed for carboxylic acid inhibitors but the concentration remains high enough to protect the copper and brass in the system to high mileages as evidenced by lack of copper and brass corrosion products in solution. As can be seen in Figure 2, the tolyltriazole level in the Factory Fill coolant (red) starts over a twice the level as the Prestone Cor-Guard (blue) but quickly approaches the level in Prestone Cor-Guard. This is because of the stable

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nature of the Cor-Guard inhibitor technology which enables it to provide corrosion protection without a dramatic drop in the inhibitor concentration.

Fig 2. Tolyltriazole Concentration vs. test mileage: ▲= Factory Fill, ● = Prestone Cor-Guard.

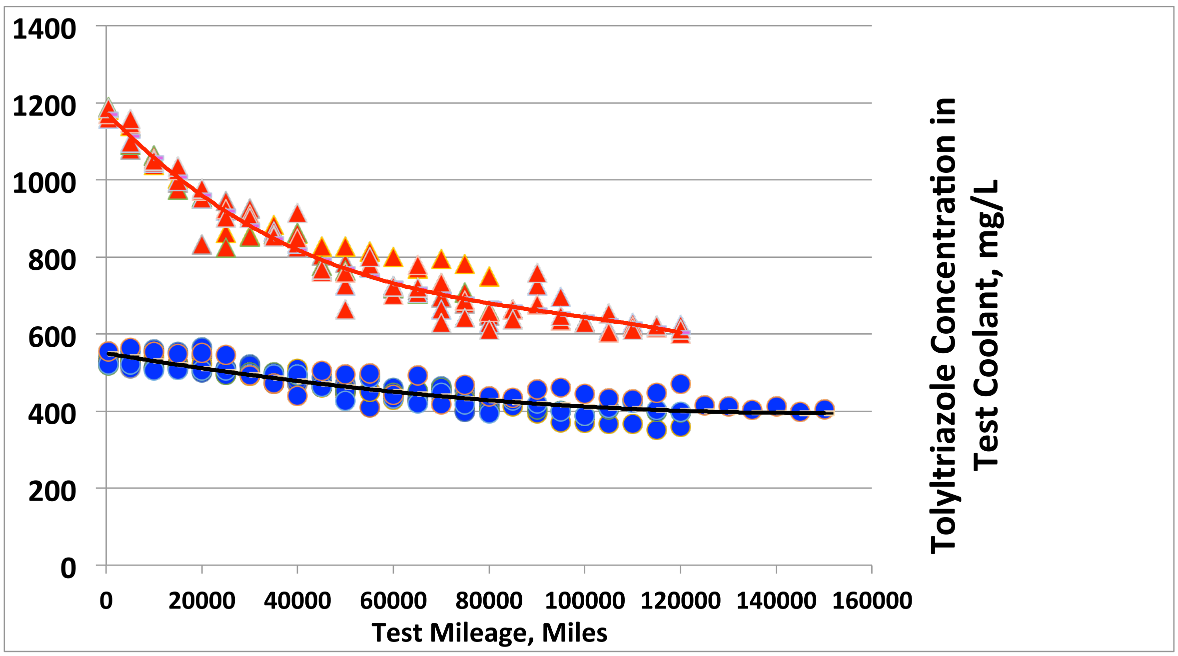

Fig 3. The average % of a Prestone Cor-Guard Key Inhibitor Concentration vs. test mileage.

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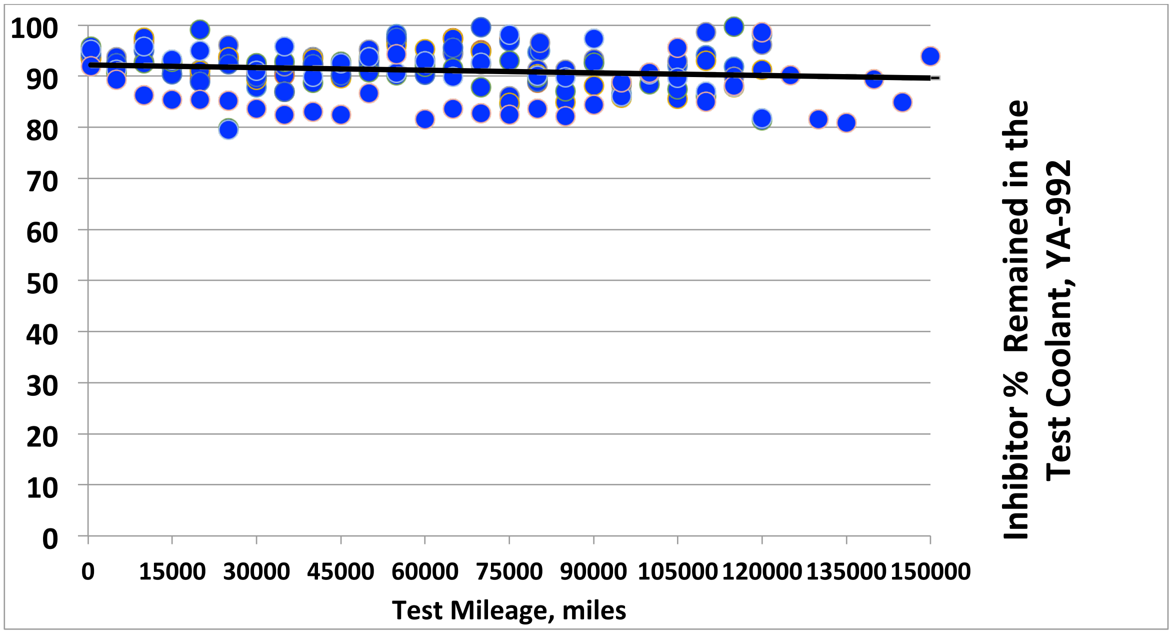

The average % azole remaining in the test coolant at 120,000 test miles was ~80% of the azole remaining for the Extended Life Cor-Guard and ~50% for the OAT Factory Fill coolant, Figure 2. In addition, another key corrosion inhibitor in the Prestone Cor-Guard, not present in the Factory Fill coolant, was tracked as a function of test mileage, Figure 3. The data shows the inhibitor concentration is stable as a function of test miles.

To help to prevent corrosion of the metal components in the engine cooling systems, it is critical to maintain the coolant pH to the optimal levels. Excessive change of coolant pH during vehicle use can negatively impact the corrosion protection performance of the coolant. Additionally, in some cases, this can result in instability of the coolant formulation leading to precipitate formation in the cooling system, which could potentially lead to flow restriction and loss of heat transfer efficiency.

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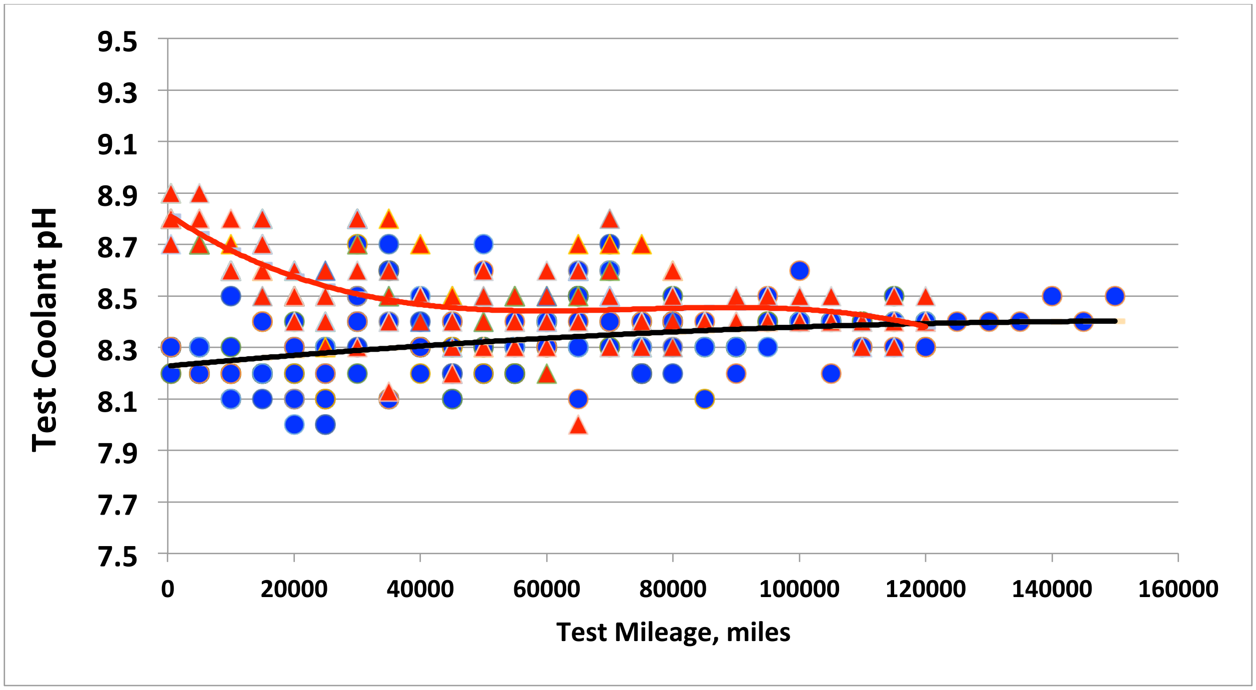
Figure 4 show the fleet test coolant pH as a function of test mileage for the 2012 Ford Fusion using the Extended Life Cor-Guard (blue) and the OAT Factory Fill fluid formulation (red).

Fig 4. Test Coolant pH vs. test mileage: ▲= Factory Fill, ● = Prestone Cor-Guard.



The results shown in Figure 4 indicate the following.

1. Test coolant pH in the fleet test using Extended Life Cor-Guard (blue) fluid formulation shows little variation with increasing test mileage, up to ~ 140,000 miles.
2. After an initial drop of 0.4 pH units for the OAT Coolant (Factory Fill coolant), the pH levels stabilized.

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In accordance with Ford protocol (Section 3.6.3 Fleet Test Validation) four of the test fleet vehicles where stopped at 80,000 miles and applicable critical components (radiator, heater core, water pump, hoses and engine cylinder heads) were removed, visually inspected, photographed and examined. Components were torn down in accordance to specific protocol and analyzed for evidence of foreign material contamination and accumulation on surfaces, corrosion, erosion, erosion-corrosion, cavitation corrosion, etc.   The remainder of the fleet continued to accumulate further mileage. The fleet testing will be stopped at a minimum of 150,000 miles and the above analysis of the components will be repeated.

The results of some of the 80,000 mile evaluation teardown of components are shown in Fig. 5-8.

The inspections indicate the following:

1. The cooling system components in the fleet vehicles using Extended Life Cor-Guard fluid formulation show very little change when compared to brand new components.
2. The aluminum cooling system components in the fleet vehicles equipped with Factory Fill product show discoloration (darkening) of the surfaces with some corrosion etching.
3. There are no corrosion or other visible deposits on the cooling system components which were protected by the Prestone Cor-Guard coolant.
4. Visible deposits accumulated on the surfaces of the radiator, heater core and cooling system hoses in the vehicles equipped with the Factory Fill fluid formulation.
5. The deposits on the heater exchangers (radiator and heater core) are aluminum corrosion products/ deposits.

Fig 5. Water Pumps (impeller –side and front views) removed from the test vehicles after 80K miles: a) Prestone Cor-Guard, Vehicle 304, b) Factory Fill, Vehicle 312.

a) Prestone Cor-Guard (side view)

b) Factory Fill Coolant (side view)

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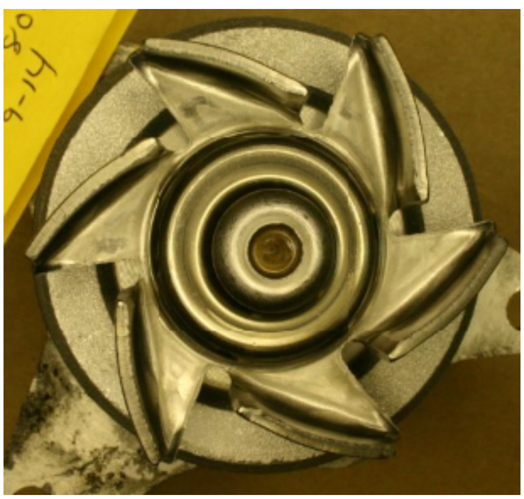
a) Prestone Cor-Guard (front view)



b) Factory Fill Coolant (front view)

Fig 6. Water Pumps (engine cover) after 80K miles. The blue arrows point to internal pump surface. The aluminum surface appears to be like new for Prestone Cor-Guard and show what looks to be gray aluminum oxide corrosion product for the Factory Fill coolant. a) Prestone Cor-Guard, Vehicle 304 b) Factory Fill, vehicle 312.

a) Prestone Cor-Guard

b) Factory Fill Coolant

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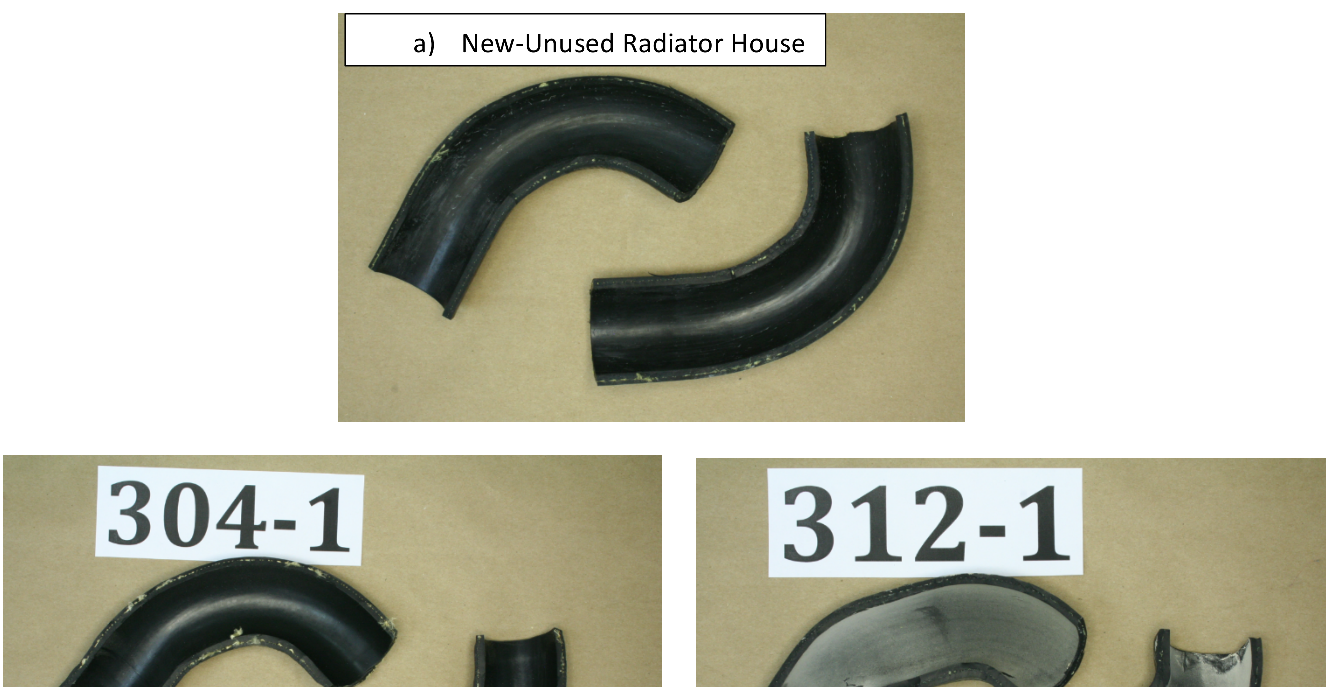
Fig 7. Radiator Hoses the have been cut open to expose the interior surface: a) New Unused Radiator Hose b) Prestone Cor-Guard, from Vehicle 304 after 80K miles c) Factory Fill, from Vehicle 312 after 80K miles.



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b) Prestone Cor-Guard coolant after 80K

c) Factory Fill coolant after 80K

Fig 8. Radiator tubes that have been cut diagonally and butterflied open to show the interior of the tube: a) New Unused Radiator tubes, b) Prestone Cor-Guard, from Vehicle 304 after 80K miles, c) Factory Fill, from Vehicle 312 after 80K miles.

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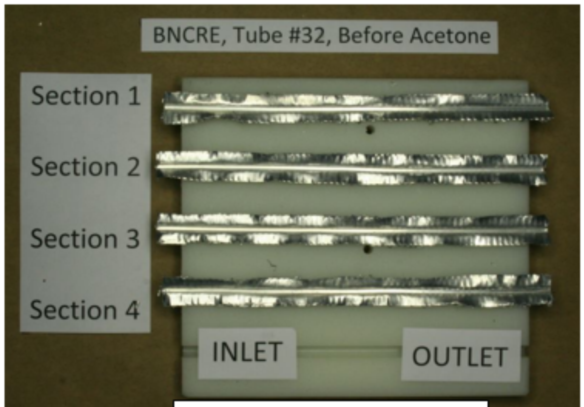
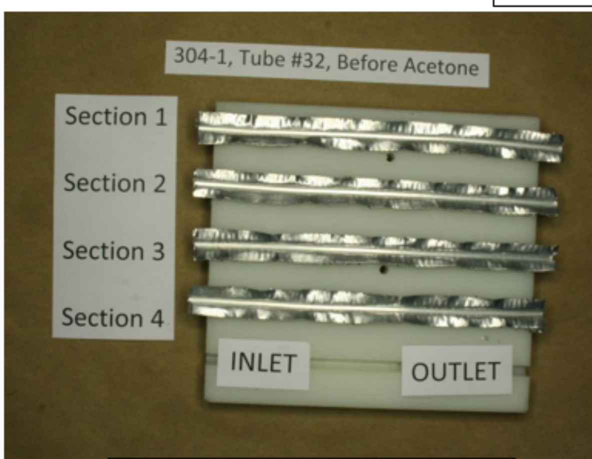
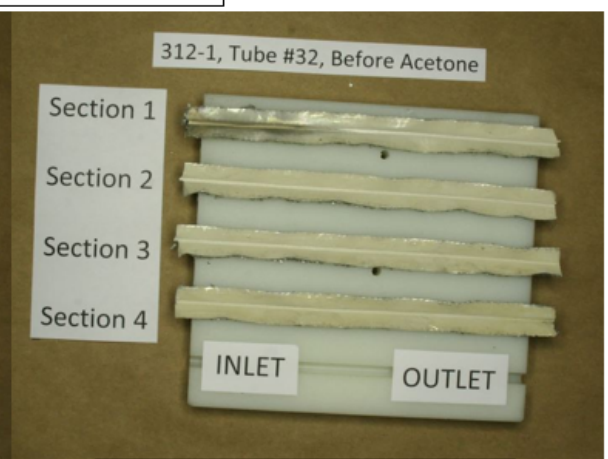


New Unused Radiator Tubes



CorGuard used Radiator Tubes at 80K



Factory Fill used Radiator Tubes at 80K

To better understand the extent of the corrosion deposit on the interior radiator and heater core tube, select tubes from each radiator were removed and brushed with a hard bristle brush to remove any lightly adhered deposits. The aluminum corrosion product deposits were collected and weighed. A summary of the results are shown in Tables 2 and 3.

The information in Tables 2 and 3 shows that in the radiators and heater cores removed from the vehicles containing Prestone Cor-Guard there are trace deposits on the surface, about what would be expected on a new radiator. For the Factory Fill vehicles, deposits were very visible and were on average over 20 times heavier in the radiator tubes and 2.5 times heavier in the heater core.

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Table 2: Radiator Tube Deposit Weights for New Radiator Tubes versus Radiator Tubes Removed from 4 test vehicles at 80,000 test miles for Prestone CorGuard versus Factory Fill OAT Coolant

	Deposit Weight, mg/ cm^2		
Radiator Tube No.	New Tube	CorGuard	Factory Fill
		Vehicle 304	Vehicle 312
2	0.01	0.12	1.22
11	0.06	0.01	0.55
20	0.05	0.04	0.42
22	0.12	0.00	0.61
32	0.10	-0.01	2.26
41	0.07	0.02	2.08
Average	0.07	0.03	1.19
	New Tube	CorGuard	Factory Fill
		Vehicle 310	Vehicle 318
2	0.01	0.06	0.89
11	0.06	0.03	0.57
20	0.05	0.05	0.51
22	0.12	0.05	0.45
32	0.10	0.05	2.22
41	0.07	0.06	2.94
Average	0.07	0.05	1.26

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Table 3: Heator Core Tube Deposit Weights for New Heater Core Tubes versus Heater Core Tubes Removed from 4 test vehicles at 80,000 test miles for Prestone CorGuard versus Factory Fill OAT Coolant

	Deposit Weight, mg/ cm^2		
Heater Core Tube No	New Tube	CorGuard Vehicle 304	Factory Fill Vehicle 312
2	0.032	0.047	0.162
5	0.039	0.021	0.159
8	0.056	0.025	0.190
11	0.064	0.011	0.167
14	0.029	0.015	0.188
17	0.039	0.033	0.165
Average	0.043	0.025	0.172
	New Tube	CorGuard Vehicle 310	Factory Fill Vehicle 318
2	0.032	0.032	0.124
5	0.039	0.066	0.101
8	0.056	0.051	0.162
11	0.064	0.051	0.098
14	0.029	0.044	0.111
17	0.039	0.044	0.140
Average	0.043	0.048	0.123

Samples of the deposits was taken from the radiator tubes of the Factory Fill vehicles (vehicles 312 and 318) and submitted for analysis. The analysis consisted of Inductively Coupled Plasma Spectroscopy (ICP) of the dissolved solid deposits. The analytical results, Table 4, shows the deposits to be mostly composed of aluminum corrosion products.

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Table 4. ICP Analysis of Deposits Collected from Radiator Tubes of Ford Fusion Fleet Test Vehicles filled with Factory Fill OAT coolant after 80,000 test miles.

Element Analysis by ICP, ppm	Deposits Collected from 6 Radiator Tubes of Vehicle 312	wt% of the element in the Deposit	Element Analysis by ICP, ppm	Deposits Collected from 6 Radiator Tubes of Vehicle 318	wt% of the element in the Deposit
Al	488900	86.53	**Al**	485700	84.62
B	--	--	B	--	--
Ca	7486	1.32	**Ca**	5851	1.02
Cu	--	--	Cu	--	--
Fe	4810	0.85	**Fe**	5392	0.94
K	11620	2.06	**K**	16020	2.79
Li	--	--	Li	--	--
Mg	--	--	Mg	--	--
Mo	--	--	Mo	--	--
Na	36390	6.44	**Na**	42520	7.41
P	--	--	P	--	--
Pb	--	--	Pb	--	--
Si	--	--	Si	3512	0.61
Sr	--	--	Sr	--	--
Zn	15800	2.80	**Zn**	14980	2.61
Sum	565006	100.00	Sum	573975	100.00

Key: " --" means "not detected".

The ability of a coolant to protect fresh metal surfaces is important for extended life coolants. In addition, the ability to provide this type of protection could be even more critical for vehicles with smaller and more powerful engines. These coolants are designed to remain in cars for a much longer time than conventional coolants and it is possible that the coolant life may be longer than that of individual components.

In that case, coolant may be returned to the cooling system after a repair and expected to prevent corrosion of the new components as well as protecting older components. To help predict the reserve corrosion inhibition in the formulation and to predict the ability of the coolant to protect the cooling system at higher mileage intervals, the end of test (EOT) fluid is evaluated. The EOT fluid was evaluated at 50% volume concentration with the addition of the corrosive salts per ASTM D1384 glassware test and D4340 aluminum corrosion test requirements.

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The results in Table 5 and 6 show that the both the Factory Fill and Prestone Cor-Guard coolants will continue to provide long-term performance beyond 5 years and 150,000 miles and will be able to protect fresh metal surfaces even after extended use.

Table 5: ASTM D 1384 Corrosion results, weight loss mg/specimen, on test coolant removed after 80,000 test miles.

	Copper	ASTM	Brass	Steel	Cast Fe	Cast Al
Car 304-1 / Car 310-1 50v% (Cor-Guard)	0.1	4.5	3.4	1.3	-0.5	-3.3
Car 312-1 / Car 318-1 50v% (Factory Fill)	1.6	3.6	2.1	-0.2	-0.8	1.6
ASTM D3306 Glassware Requirements	10 max	30 max	10 max	10 max	10 max	30 max

Table 6: ASTM D4340 Corrosion Test (mg/cm2/week)

	Water Wash	Acid Cleaned
Car 304-1 / Car 310-1 50v% (Cor-Guard)	0.1	0.1
Car 312-1 / Car 318-1 50v% (Factory Fill)	0.2	0.3
ASTM D3306 requirements	--	1.0 max

Conclusions

Prestone Cor-Guard Extended Life antifreeze/coolant has been shown by laboratory and fleet testing to provide outstanding protection to cooling system components through 80,000 miles following the Ford protocol. Per Ford guidelines, this would be give a coolant with 8 years/ 168,000 service life, well above our 5 year/ 150,000 mile performance claim. Further, the results indicate that the Prestone Cor-Guard coolant will perform better than the current reference 5 year/ 150,000 mile Extended Life OAT coolant considered in this study. The Prestone Cor-Guard provides a fast acting inhibitor package that leaves the cooling system surfaces looking like new even after 80,000 test miles. A series of laboratory tests shows that the performance of the coolant removed from the system at this time continues to provide protection of all of the cooling system metals. This is consistent with the fluid analysis of the test coolants

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showing that the inhibitor package for the Prestone Cor-Guard is remaining stable throughout the test.

1. Edmunds.com, Top 10 Best-Selling Vehicles for 2011, by Warren Clark, Automotive Content Editor, 1/12/2012
2. Edmunds.com, Top 10 Best-Selling Vehicles for 2010, by Warren Clark, Automotive Content Editor, 1/07/2011
3. Harrop, D., "Chemical Inhibitors for Corrosion Control", Chemical Inhibitors for Corrosion Control, Clubley, B.G., Ed., Royal Society of Chemistry, Manchester, 1988, pp.1-20