
A Chemical Base for Engine Coolant / Antifreeze with Improved Thermal Stability Properties

Edward R. Eaton

Amalgatech Division of Amalgamated Laboratories, Inc.

W. H. Boon and Chris J. Smith

Shell Chemical Co.

Reprinted From: Engine Coolant Technology
(SP-1612)

The appearance of this ISSN code at the bottom of this page indicates SAE's consent that copies of the paper may be made for personal or internal use of specific clients. This consent is given on the condition, however, that the copier pay a \$7.00 per article copy fee through the Copyright Clearance Center, Inc. Operations Center, 222 Rosewood Drive, Danvers, MA 01923 for copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Law. This consent does not extend to other kinds of copying such as copying for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale.

SAE routinely stocks printed papers for a period of three years following date of publication. Direct your orders to SAE Customer Sales and Satisfaction Department.

Quantity reprint rates can be obtained from the Customer Sales and Satisfaction Department.

To request permission to reprint a technical paper or permission to use copyrighted SAE publications in other works, contact the SAE Publications Group.



GLOBAL MOBILITY DATABASE

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

ISSN 0148-7191

Copyright 2001 Society of Automotive Engineers, Inc.

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE Transactions. For permission to publish this paper in full or in part, contact the SAE Publications Group.

Persons wishing to submit papers to be considered for presentation or publication through SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

A Chemical Base for Engine Coolant / Antifreeze with Improved Thermal Stability Properties

Edward R. Eaton

Amalgatech Division of Amalgamated Laboratories, Inc.

W. H. Boon and Chris J. Smith

Shell Chemical Co.

Copyright © 2001 Society of Automotive Engineers, Inc.

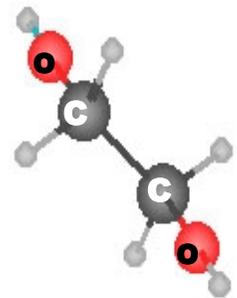
ABSTRACT

Increasingly challenging international engine emissions reductions have resulted in some advances in engine emissions technologies that may motivate a change from the customary ethylene glycol and/or propylene glycol bases that have been the mainstay of engine antifreeze formulations for almost a century. The new engines' components, especially exhaust gas recirculation (EGR) devices, generate much greater thermal stress on the engine coolant. The oxidation of ethylene glycol and propylene glycol may be accelerated dramatically, resulting in coolant unsuitable for continued use in as little as a few months. The industry has been working towards extended engine coolant service intervals^{1,2,3,4}, with some recommendations for service extended to as long as five years. It follows, therefore, that a requirement for coolant change at four to six month intervals (due to accelerated oxidation & aging) would be unacceptable to vehicle owners.

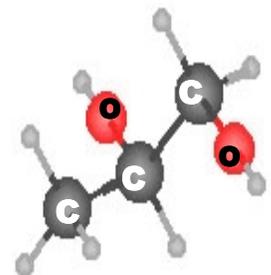
Coolants are generally evaluated and judged by subjecting them to a series of physical properties and performance tests, and then comparing the data to the specifications published by ASTM⁵. This paper reports the data generated by subjecting a new coolant base chemistry, 1,3 Propanediol (PDO), to the ASTM D3306⁶ Light and Medium Duty (Automotive) and D6210/6211⁷ "Fully Formulated Engine Coolant" physical and performance testing protocols. These protocols qualify an engine coolant for use in virtually any engine cooling system, gasoline (petrol), diesel, and natural gas; engineered with or without wet sleeve cylinder liners.

INTRODUCTION

Diesel engine OEMs are vigorously working to prepare low-emissions diesel-fueled engines that will meet the emissions requirements of North American and European regulatory agencies in the first decade of the twenty-first century. Extensive investments and research into various possible design improvements have generated some effective technologies. Some of these technologies include the introduction of exhaust gas recirculation devices (EGRs). EGR devices, as the name implies, pass part of the exhaust gas back to the combustion chamber to lower target emissions. Exhaust gases, especially those produced by a diesel engine, are much hotter than regular intake air. The EGR gases, therefore, must be cooled by the existing engine coolant system before they reach the



Ethylene Glycol
(1,2 Ethandiol)



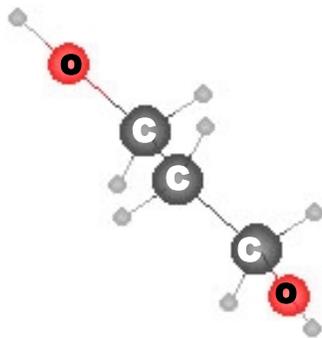
Propylene Glycol
(1,2 Propanediol)

Figure 1.1: EG & PG

combustion chamber. The authors have observed many coolant samples from prototype engines equipped with EGR systems. Unfortunately, secrecy agreements do not permit revelation of the engines or systems involved, but the authors may offer some general information.

Coolant blended from ethylene glycol (EG) for heavy-duty diesel applications in prototype EGR-equipped engines sometimes experiences discoloration and rapid oxidation. Oxidation reactions include nitrite (NO_2) to nitrate (NO_3) and ethylene glycol ($\text{HO-CH}_2\text{-CH}_2\text{-OH}$) to formic acid (CH-OOH) and glycolic acid ($\text{HO-CH}_2\text{-C-OOH}$). The data reported herein will support the conclusion that in the presence of an EGR, EG degradation is greatly accelerated. This degradation results in an increase in corrosive properties that attack engine components and cause premature failure. Although propylene glycol (PG) coolants have not been tested with EGR devices, PG is generally understood to be even less thermally stable than EG.

Shell Chemical is a major producer of ethylene oxide (EO) derivatives. In addition to EG and PG (Figure 1.1), Shell produces an isomer of propylene glycol, 1,3



'PDO'
1,3 Propanediol

Figure 1.2: PDO

DISCUSSION

BACKGROUND – Ethylene glycol (1,2 ethanediol) and propylene glycol (1,2 propanediol) have offered the lowest-cost chemical bases for engine antifreezes / coolants for many decades. The current ASTM

specifications for glycol based engine coolants are ASTM D3306 (automotive and light duty) and D6210 (fully formulated heavy duty). If EG and PG were found to be incapable of service in EGR-equipped diesel engines, PDO may offer a more stable, longer-lived alternative, providing that the fluid is proved to be capable of protecting coolant systems against corrosion and other damage in compliance with the limits set forth in the referenced ASTM specifications.

The diesel engine emissions requirements for the model year 2002 heavy-duty diesel engines have resulted in experimentation with exhaust gas recirculation (EGR) devices. Diesels with EGRs have been developed and tested in various environments. In some tests the engine coolant turned black and produced a strong, acrid, unpleasant odor. Chemical analysis of the used coolant revealed very high concentrations of formates and glycolates. In addition, the nitrite concentration had been prematurely depleted by oxidation to nitrate, as was the silicate. The coolants' pH had dropped from 10.2 to 8.3 in just a few months' service. Overall, this change results in a corrosive coolant that may attack, and cause premature failure of, cooling system components.

In order to learn if the new chemistry offered benefits compared to EG based engine coolants, three sets of ASTM D3306 / D6210 style test protocols were commissioned. These tests followed the ASTM protocol, except that the testing temperatures were increased to the maximum safe operating temperature of each performance testing apparatus. This adaptation was designed to increase the severity of the test, to simulate the increased thermal stress contributed by the EGR equipped diesel engines, and to learn if the new chemistry would resist premature aging better than EG. Each test pair included an EG and a PDO new chemistry fluid prepared per the appropriate ASTM standard test methods. Each of the three pairs represented one inhibitor chemistry.

DISCOVERIES - Research

Automotive (light duty)–The first round of tests evaluated PDO inhibited with an inhibitor package described in the GM 6043⁸ antifreeze formulation / specification. This inhibitor package, in EG, represented the factory-fill for all North American GM cars until 1994. Its properties are well known and the chemistry offered a good opportunity to assess the probable performance of PDO by using ASTM laboratory tests.

Figure 2: Freeze Point Characteristics of PDO Compared to EG-Based Coolant (°C).

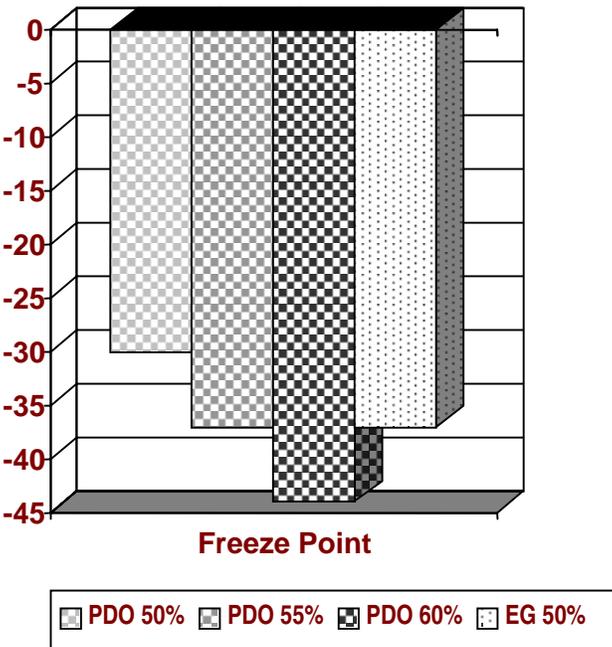


Figure 2 illustrates the aqueous solution freeze point characteristics of the GM 6043 PDO and GM 6043 EG.

Table 1.1 Physical Tests There is a slight compromise of the freeze protection as determined by the ASTM D1177⁹ test method, but the scientist performing the test noted that the PDO was distinctly softer and more wet in the characteristically slushy phase of diols at the determined freeze point. This could be an indication that actual protection against hard, damaging freezing is actually better, approaching the effective protection point of the EG-based product. The authors also performed the D1177 test with 55% and 60% PDO in water, and found that the 55% concentrated product offered protection equivalent to 50% EG, per the test method. Freeze protection continued to improve at 60% PDO. The authors feel that the antifreeze properties of the chemistry are acceptable; indeed a 50% solution would provide adequate protection against freezing in most geographies. Table 1.1 shows the following:

The boiling point of the 50% solution by ASTM D1120 is 106°C, one degree lower than the 50% EG at 107 °C. PDO has a slightly lower specific gravity (SG) than EG when measured by the ASTM D1122 method. The EG based antifreeze was found to have a SG of 1.129 whereas the PDO SG was measured at 1.070. Neither coolant had any effect when subjected to the effect on automotive finish evaluation (ASTM D1882). Indeed, as

Table 1.1: Physical Properties: Light Duty

| Test Number & Description | PDO 6043 | GM 6043 (EG) |
|---------------------------------------|------------------------------|-----------------------------|
| D1122 Specific Gravity | 1.070 | 1.129 |
| D1177 Freeze Point 50% vol. in water | -28 °C (-18 °F) | -38 °C (-36 °F) |
| D1120 Boiling Point 50% vol. in water | 106 °C (222 °F) | 107 °C (226 °F) |
| D1882 Auto Finish Effect | none | none |
| D1119 Ash Content | 0.81 % | 0.87% |
| D1287 pH: 50% vol. in DI water | 9.8 | 8.67 |
| D3634 Chloride | 16 | 11 |
| D1123 Water, mass percent | 4.1% | 4.0% |
| D1121 Reserve Alkalinity | 9.8 | 9.3 |
| D1881 Foaming Tendencies | Break 3.6 Sec Vol. 113 ml | Break 1.6 Sec Vol. 50 ml |

Table 1.2: Glassware Testing Data Light Duty

| Test Number & Description | PDO 6043 | GM 6043 (EG) |
|--|--|--|
| D4340 Corrosion of Aluminum Heat Rejecting Surface | 0.27 mg/cm ² /week | 0.12 mg/cm ² /week |
| D1384 Corrosion in Glassware | Cu 3 mg Solder 1 mg Brass 2 mg Steel 1 mg Cast Fe 2 mg Cast Al 0 mg | 3 mg 1 mg 2 mg 1 mg 1 mg 0 mg |

Table 1.3 Simulated Service Tests Light Duty

| Test Number & Description | PDO 6043 | GM 6043 (EG) |
|-------------------------------------|--|--|
| D2570 Simulated Service | Cu 3 mg Solder 0 mg Brass 7 mg Steel 1 mg Cast Fe 0 mg Cast Al 4 mg | 5 mg 4 mg 0 mg 3 mg 3 mg 1 mg |
| D2809 Water Pump Cavitation-Erosion | 8 | 8 |

reflected in tables 1.1 – 1.3, 2.1 to 2.3 and 3.1 to 3.3, many of the physical properties of the two coolants are very similar. The similarity is beneficial, because the new coolant will almost certainly be contaminated from time to time with EG and/or PG based coolants. When contamination occurs, it would be desirable that no harm

Table 2.1 Physical Properties: HD type A

| Test Number & Description | PDO 6210 'A' | Control EG 6210 'A' |
|--|-----------------------------|-----------------------------|
| D1122 Specific Gravity | 1.067 | 1.127 |
| D1177 Freeze Point 50% vol. in water | -30 °C (-21 °F) | -38 °C (-36 °F) |
| D1120 Boiling Point 50% vol. in water | 107 °C (226 °F) | 107 °C (226 °F) |
| D1882 Auto Finish Effect | No effect | No effect |
| D1119 Ash Content | 0.55% | 0.80% |
| D1287 pH: 50% vol. in DI water | 11.25 | 11.0 |
| D3634 Chloride | 24 | 25 |
| D1123 Water, mass percent | <3.0% | <3.0% |
| D1121 Reserve Alkalinity | 6.8 | 8.8 |
| D1881 Foaming Tendencies | Break 3.3 Sec Vol. 65 ml | Break 2.1 Sec Vol. 55 ml |

Table 2.2: Glassware Testing Data HD type A

| Test Number & Description | PDO 6210 'A' | Control EG 6210 'A' |
|--|--|---|
| D4340 Corrosion of Aluminum Heat Rejecting Surface @150 °C | 0.28 mg/cm ² /week | 0.20 mg/cm ² /week |
| pH Before & After Test | 11.3 & 8.6 | 11.0 & 8.2 |
| D1384 Corrosion in Glassware @ 150 °C | Cu 3 mg Solder 2 mg Brass 2 mg Steel 1 mg Cast Fe 0 mg Cast Al 4 mg | 4 mg 26 mg 2 mg 1 mg 0 mg 0 mg |

Table 2.3: Simulated Service Tests: HD type A

| Test Number & Description | PDO 6210 'A' | Control EG 6210 'A' |
|-------------------------------------|--|---|
| D2570 Simulated Service @ 87 °C | Cu 12 mg Solder 11 mg Brass 4 mg Steel 3 mg Cast Fe 0 mg Cast Al 0 mg | 8 mg 56 mg 1 mg 1 mg 1 mg 0 mg |
| D2809 Water Pump Cavitation-Erosion | 8 | 3 |

to the system result. Presumably, only some of the anti-oxidation benefit would be lost.

The water content of the antifreeze is contributed by the inhibition technology, so there is no difference in the two base alternatives. Similarly, pH, chloride and ash characteristics were equivalent. The foaming tendency of the PDO was slightly higher, but remained within the ASTM D3306 limits. (Tables 1.1, 1.2, 1.3) Inhibited with the GM 6043 chemistry, the PDO performed as well as EG in the modified ASTM-type tests.

The data reported to this point in the paper were developed to learn if PDO had potential as an engine coolant. The data prove that the properties of the new chemistry are favorable, and justified further research. The next stage of research targeted commercial fleet engines.

Fully Formulated (heavy duty)—The second round of tests evaluated PDO as a heavy-duty or 'universal' fleet-targeted coolant. This course of testing was undertaken because reports had reached the authors that EG-based coolants in heavy duty diesel trucks equipped with prototype EGR devices were turning black and corrosive in less than three months / 50,000 km. To determine the viability of PDO as a heavy-duty coolant, it was prepared with both the ASTM D6210 type inhibitor chemistries. The chemistries are generally described in paragraphs A 1.2.1 (referred to henceforth in this paper as 'type A') and A 1.2.2 (type 'B'). These chemistries, in addition to the requirements that they meet the performance specifications for cars and light trucks, are required to contain chemistry to protect heavy-duty diesel engines commonly engineered with wet sleeve liners against cavitation-erosion. The tests were run against a similarly inhibited EG control. The coolant samples were all prepared in the laboratory, using the same inhibitor provided by two major inhibitor manufacturers.

PDO appears to offer intriguing advantages. The customary data is reported in Tables 2.1 - 2.3. They reveal potential advantages in corrosion protection, in particular, protection against lead solder corrosion. The authors remind the reader that these tests were run at higher temperatures, where possible, than is specified by ASTM D6210, so these data should not necessarily be viewed as 'pass' or 'fail' per the standard, but as research experiments.

In the elevated temperature aluminum heat rejection test, based on D4340, reported in Table 2.2, the coolants were operated for 168 hours at 150 °C. The standard method specifies 168 hours at 135 °C. Similarly, the temperature was elevated in the D1384 and D2570 to the maximum sustainable in the equipment. The operating temperature modifications are noted in the data tables, 2.1 to 2.3, below:

The data are interesting in that, in this set of tests, two annoying tendencies of "type A" formulations are soundly dampened by the PDO. Namely, higher solder corrosion in D1384 and D2570 and the inconsistent water pump erosion performance sometimes seen in the D2809, as was reported in this sequence.

An additional test was engineered. As coolant ages in use, some of the glycols oxidize. Samples of the control 'type A' and PDO 'type A' coolants were blended at 50% and heated at 150 °C for 28 days in an ASTM D4340 test rig (no corrosive water was added). Ethylene glycol may form formic acid, glycolic acid or oxalic acid. PDO was analyzed for these and larger C₃ carboxylates, in case degradation of the PDO molecule might produce them.

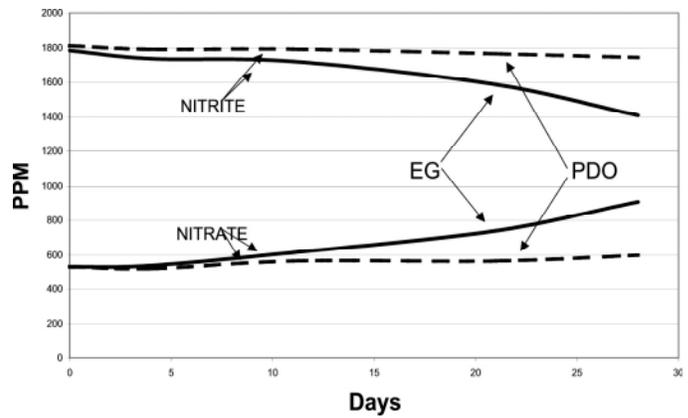


Figure 4: Nitrite and Nitrate Behavior

PDO type 'A' and type 'B' both produced very positive data. In the higher temperature testing, data either were equivalent to or better than the EG. Significant improvements were documented in lead solder performance, aluminum water pump erosion/corrosion and degradation of PDO. Corrosion in glassware, the ASTM D1384 method, was performed with the standard set of six metal samples. Type 'B' data for each the six metals are reported in table 2.2. The standard test requires 336 hours of exposure at 88 °C. This test was run for 336 hours at 150 °C by using a propylene glycol bath instead of water. Similarly, The coolant temperature was elevated in the D4340 apparatus.

The maximum safe operating temperature of the standard simulated service rig was deemed to be 93°C, five degrees warmer than the normal operating temperature of 88°C. In general, the data from the simulated service paralleled that of the corrosion in glassware test.

Finally, the two coolants were evaluated in a hot surface scale rig. There are currently no ASTM requirements or suggestions for limits in scale formation resulting from this method. The proposed method involves introducing a fluid consisting of 8 vol% of the sample mixed in corrosive hard water into the test apparatus. The apparatus is operated for 100 hours, exposing the sample to a hot steel surface in order to learn if the chemistry can prevent the formation of scale. The control 'type A' performed somewhat about the same as the PDO 'type A'. The EG control generated 1.6 grams of scale and the PDO 2.3 grams. This data suggests both coolants would require additives to prevent scale formation in service with hard water, although the 'type A' formulation technology has exhibited positive fleet experience.

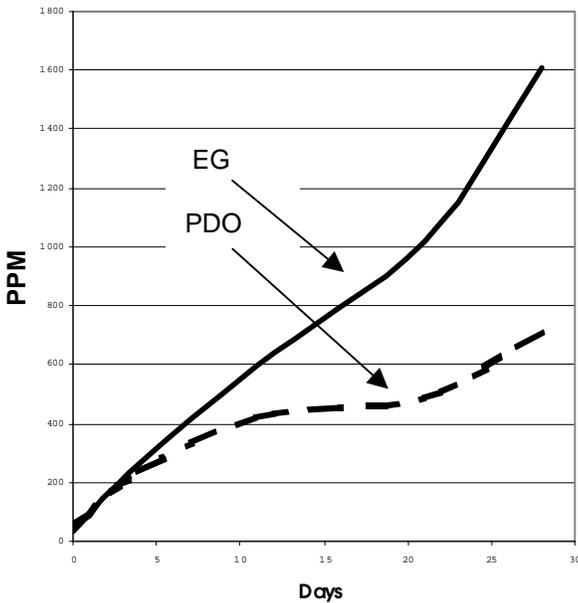


Figure 3: Oxidation Products vs. Time

Figure 3 illustrates the behavior of the coolants' degradation acids. This data suggest that high temperature characteristics of PDO may be better, that it may resist oxidation degradation better than EG.

Figure 4 illustrates the behavior of nitrite. It is intriguing to observe that the nitrite concentration is extremely stable in the PDO while the nitrite manifests a classical and expected oxidation to nitrate in EG. There are no metals in this test; pure oxidation is the only depletion mechanism.

With type 'B' inhibitor, PDO offers equivalent to slightly better corrosion protection evidenced by modified D1384 and D2570 data. In particular, chemical analyses of the coolants were conducted to quantify and compare the degradation of coolants as evidenced by the concentration of oxidation products.

The research next turned to repeating the testing using type 'B' Inhibitor. The PDO surprised the researchers by displaying unexpected reactions in the course of blending the 'type B' formulation; it gelled. Although a most intriguing event, this behavior was not useful in the evaluation of the product as an engine coolant. Experimentation finally succeeded in a method that required first blending the 'type B' inhibitors in water and then adding the PDO to successfully produce the prototype 50% prediluted coolant product. If marketed, this variation may only be available as a "ready-to-use" coolant. Of course, further formulation work certainly may find a way to overcome this most peculiar property.

The 'type B' chemistry differs from the 'type A' in that it includes phosphate in place of borate as a pH buffer and adds molybdate and an additional anti-cavitation inhibitor for wet-sleeve lined diesel engines. The two types of heavy-duty coolants herein evaluated are approximately equally represented in North American fleets. Type 'B' may be a bit more common in the global marketplace. Chances are that the final formulations for both variations will be optimized for PDO. Each of the two has produced interesting data, each had advantages and disadvantages over the other. In PDO, an optimized chemistry may offer an excellent performing product that offers long service intervals and superior corrosion protection. The data for the Type 'B' formulation follows in tables 3.1, 3.2 and 3.3.

The hot scale test was also performed on the PDO type "B". There was no scale formed on the hot surface (0.0 mg). The test stand was inspected, and the correct operation of the rig and execution of the of the procedure has been verified. The EG control experiment generated 0.18 g of scale.

The data from the type 'B' experiments are similar to the data from the type 'A'. There is evidence that the oxidation of the coolant is faster in EG than in PDO. This evidence is that the formates and glycolates are significantly lower in PDO than in EG-based coolant.

A field refractometer and coolant test strips to measure the approximate concentration and corresponding freeze point of PDO coolants is in development. Laboratory methods to monitor the quality and performance of PDO coolants are also being refined. The authors expect such methods to include at least conventional wet chemistry, ion chromatography, liquid chromatography, atomic absorption spectrophotometry and emissions methods.

Table 3.1 Physical Properties: HD type B

| Test Number & Description | PDO 'B' | EG 'B' |
|--|---------------------------------|-----------------------------|
| D1122 Specific Gravity | 1.062 | 1.135 |
| D1177 Freeze Point 50% vol. in water | -30 °C (-21 °F) | -38 °C (-36 °F) |
| D1120 Boiling Point 50% vol. in water | 107 °C (226 °F) | 108 °C (228 °F) |
| D1882 Auto Finish Effect | No effect | No effect |
| D1119 Ash Content | 1.58% | 1.76% |
| D1287 pH: 50% vol. in DI water | 10.6 | 10.5 |
| D3634 Chloride | 10 | 10 |
| D1123 Water, mass percent | <3.0% | <3.0% |
| D1121 Reserve Alkalinity @ 50% | 11.0 | 10.8 |
| D1881 Foaming Tendencies | Break 4.2 Sec Vol. 215 ml | Break 2.2 Sec Vol. 85 ml |

Table 3.2: Glassware Testing Data HD type B

| Test Number & Description | PDO 'B' | EG 'B' |
|--|--|---|
| D4340 Corrosion of Aluminum Heat Rejecting Surface @150 °C pH Before & After Test | 0.32 mg/cm ² /week 10.6 & 10.0 | 9.0 mg/cm ² /wk 10.5 & 10.0 |
| D1384 Corrosion in Glassware @ 150 °C | Cu 2 mg Solder 2 mg Brass 1 mg Steel 2 mg Cast Fe 0 mg Cast Al 0 mg | 1 mg 2 mg 2 mg 5 mg 7 mg 0 mg |

Table 3.3: Simulated Service Tests: HD type B

| Test Number & Description | PDO 'B' | EG 'B' |
|--|--|---|
| D2570 Simulated Service @ 87 °C | Cu 3 mg Solder 1 mg Brass 8 mg Steel 2 mg Cast Fe 0 mg Cast Al 1 mg | 1 mg 58 mg 1 mg 0 mg 0 mg 8 mg |
| D2809 Water Pump Cavitation-Erosion | 9 | 8 |

CONCLUSIONS

A prospective new base chemical has been discovered that resists oxidation due to thermal stress better than ethylene glycol. The chemistry, Shell Chemical's 1,3 propanediol or PDO, may be successfully inhibited with conventional light duty and fully formulated heavy-duty inhibition technologies. The coolant base has passed all of the high temperature-modified ASTM type tests, demonstrating PDO's capabilities in severe operating environments.

Continuing work to certify the chemistry to existing ASTM engine coolant performance standards is being conducted, but the coolant is expected to pass, given that it has already succeeded under more severe test conditions. Inhibitor package optimization for use in PDO may offer additional benefits in the final development of an extended service coolant technology.

Another phase of research should investigate the behavior of PDO inhibited with extended service inhibitor chemistry, such as that used in the Caterpillar and Texaco extended service products based on 2-ethylhexanoic acid and sebacic acid carboxylate inhibitors. It will also include various 'hybrid' formulations such as are preferred by John Deere, Ford and Daimler-Chrysler.

ACKNOWLEDGMENTS

The authors appreciate the contributions of Amalgatech, The Penray Companies, Inc., Dober of Glenwood, Inc. and especially Shell Chemical Company in making this research possible.

REFERENCES

1. Edward R. Eaton. and Heather S. Eaton, "Extended Service of 'Fully Formulated' Heavy Duty Antifreeze in American Cars". *Engine Coolant Testing*, Fourth Volume, ASTM STP 3315, R. E. Beal, Ed., American Society for Testing and Materials, West Conshohocken, PA, 1997
2. R. D. Hudgens and R. D. Hercamp, A Perspective on Extended Service Intervals and Long Life Coolants for Heavy Duty Engines, SAE paper 961818, Warrendale, PA 1996.
3. Sarkis S. Aroyan and Edward R. Eaton, "Fleet Test Evaluation of Fully-Formulated Heavy-Duty Coolant Technology Maintained with a Delayed-Release

Filter Compared with Coolant Inhibited with a nitrated Organic Acid Technology", *Engine Coolant Testing*, Fourth Volume, ASTM STP 1335, R. E. Beal, Ed., American Society for Testing and Materials, West Conshohocken, PA, 1997

4. Eaton, E. R. and Carr, R. P., "Observations of the Reliability Effects of Operating Heavy Duty Diesel Engines with a Nitrite / Borate / Low Silicate Coolant with No Coolant Change Interval", SAE paper 960642, Warrendale, PA 1996.
5. *Engine Coolants, Halogenated Organic Solvents and Fire Extinguishing Agents; Industrial and Specialty Chemicals*, Standards on Disk, American Society for Testing and Materials, West Conshohocken, PA, vol 15.05, 2000 D3306-00
6. *Ibid* D4985-00
7. *Ibid* D6210 and D6211
8. GM 6043 Standard Coolant Formulation, General Motors Corporation, Detroit, MI
9. ASTM Standards on Disk, D1177-94

CONTACT

Edward R. Eaton, Amalgatech Division, Amalgamated Laboratories, Inc. 13901 N 73rd St, Scottsdale, AZ 85260
Telephone: 480-556-0888, Fax: 480-991-2903; e-mail: ereaton@amalgatech.com

DEFINITIONS, ACRONYMS, ABBREVIATIONS

ASTM – American Society for testing of Materials

EG – Ethylene Glycol (1,2 ethanediol)

EGR – Exhaust Gas Recirculation device

GM – General Motors Corporation

OEM – Original Equipment Manufacturer (s)

PDO – (1,3 propanediol)

PG – Propylene Glycol (1,2 propanediol)