Engine Coolant Testing

Fourth Volume

Roy E. Beal, editor

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Foreword

The Symposium on Engine Coolant Testing was held 5–7 November 1997 in Scottsdale, Arizona. Committee D15 on Engine Coolants sponsored the symposium. Roy E. Beal, Amalgamated Technologies, Inc., presided as symposium chairman and is editor of this publication.

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Overview

The Fourth Symposium on Engine Coolants demonstrated many advances and changes in the technology of coolants and their testing procedures. A gradual globalization of coolant formulation is occurring in parallel with the world production of specific vehicles that meet the demands of several disparate markets. There are still important differences in the direction of technology in the United States, Europe, Japan, and the rest of the world. There is now a more widespread acceptance that usefully constructed coolants should be used in any location. New engine designs demand coolant fluid discipline. Organic acid basic inhibitor technology is the growth area with continued interest in propylene glycol as a substitute for the more commonly used ethylene glycol. The new work is in extended life coolants. Major vehicle manufacturers are now recommending 10 years or in some instances life of vehicle coolants. These factors will slow the total volume of coolant required somewhat, but the total world vehicle population is increasing at the same time. There is continued interest in the development, management, and quality control of the modern engine for both OEM and after-market, which is the main purpose of ASTM D15 Committee as the standards body responsible for guiding a consensus towards agreed levels of technical competence to serve an increasingly sophisticated vehicle market.

The first symposium was held in Atlanta, Georgia, in 1979, and papers presented were published in STP 705, which is still a practical, as well as historical volume. Rapid changes in material usage with more aluminum radiators and cylinder heads required inhibitor package modifications and new tests, covered in the second ASTM Engine Coolant Testing conference in 1984. A hot surface protection standard had been developed and propylene glycol was introduced. Electrochemistry was highlighted and heavy duty vehicles received attention. Presented papers were published in STP 887.

A third ASTM Engine Coolant Symposium followed in 1991 which was truly international in character with presentations from Europe, Japan, and the United States. Organic acid based inhibitors were introduced, work on sebacic acids, and typical alkaline phosphate silicate formulas prevalent at the time in the United States were covered. Cavitation of diesel engine liners and protection, pump seal evaluations, and recycling of coolant were other major areas presented. Papers can be found in STP 1192, the third volume in the Engine Coolant Testing Series. A look at all three volumes as a compendium reveals an excellent collection of technology in the field and together with this fourth book, makes the most comprehensive review of the engine coolant world past and present with a brief look at its possible future.

The symposium opened with papers on organic acid inhibitor technology lead by Tom Weir who covered testing of organic acids by examination of the effectiveness of thirty organic acids using electrochemistry, glassware, and galvanic methods. In general, aliphatic monoacids provide good aluminum alloy protection, but are antagonistic to solders. Aromatic monoacids can be good on steels and cast iron. Longer chain acids tend to provide better protection. Several organic acids with good overall performance were identified.

The composition of incipient passivating layers on heat rejecting aluminum in carboxylate and silicate inhibited coolants was the title of the Wagner et al. paper, where correlation with ASTM D 4340 weight losses was reported. X-ray photoelectron spectroscopy identified the compositional differences between the coolants on 319 aluminum alloy surfaces under heat

rejecting conditions. Silica was the primary layer in silicated coolants with hydrated alumina formed in the organic acid coolant family. The role of the carboxylate inhibitors is suggested as a promoter of highly protective forms of hydrated alumina on converted metal surfaces, where the silica layer is purely exogenous. Mixtures of the two coolants produced increased corrosion and less protection, especially at lower 25% glycol levels, where low levels of cross contamination produced significant loss of protection. Clearly, contamination is to be avoided until a protective layer is created on the surface of the components involved with either the silicated or carboxylic inhibited packages.

Fleet test evaluations of fully formulated coolants for heavy duty application were compared with a standard supplemental coolant additives (SCA) filter charge program. Ethylene glycol based coolant with phosphate-silicate, nitrited carboxylic acid technology and a phosphate-free low silicate formula in propylene glycol were investigated by Aroyan and Eaton. Results demonstrated that a nitrited carboxylic acid inhibited coolant was similar in performance to the more conventional coolant inhibitor approach in both ethylene and propylene glycol bases. All technologies were providing acceptable protection in a 66 fleet test program.

The overall performance of conventional coolant inhibitor technology compared to the newer organic acid technology has not been previously reported and was investigated by D. E. Turcotte et al. The depleting nature of silicates during service has led to a conservative coolant change recommendation of 30 000 to 50 000 miles (48 279 to 80 465 km) in automobiles. Laboratory bench, engine dynamometer, and vehicle service studies were made with the two inhibitor families. A new electrochemical test was introduced to examine passivation kinetics on aluminum alloy surfaces. Results show that silicate coolants act more quickly and passivate aluminum surface faster than the organic acid coolant. Dynamic erosion/corrosion tests tend to favor silicate technology. Both silicate and organic acid coolants provide equally long service life when adequately formulated. The main advantage of organic acid technology appears to be meeting chemical limitations imposed by some global coolant specifications.

Bartley et al. studied the depletion of tolyltriazole in testing and in service, in extended life coolant using organic acid coolant technology. Electrochemical polarization experiments indicate that the tolyltriazole forms a surface layer on copper alloys that is very protective. Laboratory tests and radiators retrieved from field tests demonstrate the effectiveness of the tolyltriazole inhibitor in conjunction with organic acid inhibitor packages. Simulated rapid coolant aging was achieved by adding finely divided powders of aluminum, iron and copper to the coolants exposed in glassware at about 105°C in air under atmospheric pressure. Results from analyses of periodically withdrawn samples correlated well with service experience. Good copper protection is achieved with tolyltriazole depletion matching laboratory and field observations.

The wide range of metals used in vehicle engine and cooling circuits requires careful consideration of the chemical complex that forms an inhibitor package. Beal reviewed corrosion aspects of the metals involved, preferred protection processes, and likely contaminants in water that reduce coolant effectiveness. Information was gathered from the general corrosion literature as it pertains to coolant, and some of the current standards for testing were discussed. The desire for longer life engine coolants emphasizes the need for newer test methods to simulate these requirements and provide needed protection.

Predictive tools for coolant development enhance experimental studies. Gershun and Mercer have defined an accelerated aging procedure for modeling fleet test results. The program objective was to predict coolant composition effects after 100 000 miles (160 930 km) or more. Cooling system metals used, their respective surface areas and coolant conditions were utilized. Degradation products, inhibitor depletion, reduction in pH and the presence of corrosion products in solution were monitored. Test coolants were evaluated by ASTM D 1384 glassware and ASTM D 4340 hot surface tests. The test procedure developed produces coolant that

compares favorably in composition, physical properties and performance with fleet test fluid. A rapid evaluation of the effectiveness of a coolant inhibitor package after 100 000 miles (160 930 km) can be performed using the procedure and is useful in the selection of competing formulas.

Rapid electrochemical screening and correlation with ASTM D 1384 glassware tests was reported by Doucet et al. The objective was to identify promising coolants more quickly, to accelerate testing and reduce coolant evaluation time and cost. Some success was claimed with a triad galvanic corrosion rate test providing the best correlation. Other tests were promising, but further work is needed.

Elastomers are very important, since most cooling systems involve several hoses under the hood. However, there are presently no standard ASTM elastomer evaluation procedures for coolant compatibilities. A session devoted to this subject was well received. Long-term service of elastomers was studied by Bussem et al. Aging effects do occur that influence physical and chemical properties over a long time period. The authors identified FEPM materials as the elastomer of choice at present for engine coolant application. Greaney and Smith used high temperature, short time immersion testing to determine the usefulness of a variety of elastomers and plastics in coolant, covering hoses, radiator tanks, and water pump seals. All of the materials tested showed some degradation after exposure to diluted or concentrated coolants with both ethylene and propylene glycol bases. Currently used inhibitor packages covered conventional, hybrid and organic acid technologies, which all similarly influenced the chosen elastomers. Evaluations included immersion tests, overflow bottle effects, post fluid analyses, tensile properties, and physical values.

Degradation of EPDM hoses by electrochemical attack was studied by Vroomen et al. covering the influences of engine coolant composition or behavior in service conditions. EPDM has been used for over 25 years, and a service problem was identified with cracking failure in hoses. Investigation had primarily explored factors involved except for the coolant. Using a laboratory test with a stainless steel holder and specimens under mechanical strain, an electrical current is forced through the essentially insulating material by having the specimen serve as the anode, and the holder is the cathode. Sulfur cured hoses are more susceptible than peroxide cured hoses to the cracking phenomenon. Collectively, these papers provide a direction to understanding the needs of a test protocol for nonmetallic materials and their response in coolants.

Heavy-duty coolants for diesel and larger trucks have particular operating requirements. Carr assessed the validity of conductivity measurement to estimate total dissolved solids and determined that it gives satisfactory data with controlled dilution. Chen and Kershisnik looked at scale deposits in high heat rejection conditions. Key parameters were evaluated and a quantitative relationship of scale formation, water hardness, and heat flux was observed. Water soluble polymers do prevent scale deposits. Glassware hard-water compatibility tests do not predict scale or deposit formation results demonstrated by the new test procedure. An extended service coolant filter development was covered by Mitchell and Hudgens, depending upon time release concepts that worked actively up to 140 000 miles (225 302 km).

Engine coolant recycling has not become as pervasive as earlier thought possible, but the industry is still growing. Large-scale recovery by distillation was reviewed by Frye et al., claiming that 15 million gal (57 million L) per year are recovered this way. Industry practices are presented with confirmation that ASTM specification engine coolants can be reliably produced by recycling. Reverse osmosis has proved itself as a suitable technology applied to engine coolant recycling. Haddock and Eaton explain the process and their experience. The technique is used in both stationary large plants and for mobile application as described by Kughn and Eaton using similar process equipment. A multistage chemical recycling process is described by Woyciesjes and Frost with extensive fleet testing to prove the method. Excellent protection

is demonstrated in heavy-duty fleets. An important caveat is that all recycling technologies do not work as well. General Motors recognized the need for a totally independent assessment of recycled engine coolants and has undertaken an approval program for automotive application. An evaluation of various processes was covered by Bradley with the development of a selection protocol.

Engine coolant testing methods that delineate protection and service capabilities are incorporated into ASTM standards by consensus. McCracken and Beal described some new procedures and proposed changes to existing methods that will strengthen the testing standards including ASTM D 4340, D 3147, D 2809, and D 2570. Possible new dynamic coolant tests are discussed. The importance of silicate stabilization to effective aluminum alloy protection was investigated by Schwartz. Results of experiments illustrate formula dependent behavior. An overview of engine coolant testing in Europe with particular reference to Germany was presented by Brösel. The well known FVV test is undergoing complete revision. A new hot test apparatus has been devised with dynamic recirculation and direct heat transfer simulation. The test comprises a modular approach with various samples in the circuit. The cavitation test is also under revision and final plans are not yet complete. The proposed tests are intended to reflect modern engine conditions for stressful operation to ensure satisfactory coolant formulation for long-service life.

Quality assessment of engine coolant production for specific formulations is vital to a consistent product. Starkey and Couch described manufacturing and quality control considerations to obtain a satisfactory output. Eaton reported on extended service fully formulated heavy-duty engine coolant experience in automobile service. Vehicle tests demonstrated satisfactory coolant performance. A new coolant filter and conditioning system applicable to automotive and truck manufacturers was reported by Wright with field test evaluations.

A successful symposium with good attendance was achieved. Some controversial presentations were made, but were certainly thought provoking for the future of coolant technology. Thanks are expressed to all the authors, the symposium subcommittee, and ASTM staff with special mention of Gloria Collins for her help throughout. The volume extends an excellent series on the progression of the engine coolant industry.

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Organic Acid Inhibitor Technology

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Testing of Organic Acids in Engine Coolants

ABSTRACT: The effectiveness of 30 organic acids as inhibitors in engine coolants is reported. Tests include glassware corrosion of coupled and uncoupled metals, FORD galvanostatic and cyclic polarization electrochemistry for aluminum pitting, and reserve alkalinity (RA) measurements. Details of each test are discussed as well as some general conclusions. For example, benzoic acid inhibits coupled metals well but is ineffective on cast iron when uncoupled. In general, the organic acids provide little RA when titrated to a pH of 5.5, titration to a pH of 4.5 can result in precipitation of the acid. Trends with respect to acid chain length are reported also.

KEYWORDS: corrosion, organic acids, long-life, coolants, glassware corrosion, electrochemistry, lead, copper, brass, cast iron, aluminum, steel

Inhibition by individual organic acids in coolants is reported to fill the literature gap between single metal inhibition by lone acids and multimetallic inhibition by acid combinations. Literature and patents [1] related to coolants provide a selection of organic acids to test for corrosion inhibition performance in ASTM and electrochemical tests. Some literature references (for example, Hersch et al. [2] and A. D. Mercer [3]) report inhibition by a large number of acids on a range of metals using a one-acid-on-one-metal approach. Others (for example, Maes [4] and W. C. Mercer [5]) report corrosion results for mixtures of acids either on single metals or the typical metal specimen bundle of ASTM Standard Test Method for Corrosion Test for Engine Coolants in Glassware (D 1384). Patents are invariably concerned with synergistic mixtures of various acids. What is missing is testing of individual acids using typical multimetallic ASTM methods and extensions.

Thirty tested acids fall into three broad categories, aliphatic monoacid, aromatic monoacid, and aliphatic diacid. These acid types appear to provide the best corrosion protection based on literature reports. Also, trends associated with acids within a particular type are investigated. For example, the linear aliphatic monoacids from C_3 to C_{12} are progressively less soluble.

General corrosion of multimetallic specimen bundles and aluminum pitting are the focus of testing. Coupled (as in D 1384) and uncoupled multimetallic bundles are considered. The coupled bundle is used for familiarity and nominal similarity to an automotive cooling system. The uncoupled bundle provides a link between single and coupled metals, is applicable to single metal cooling systems, and identifies coupling effects (in conjunction with the coupled bundle). Aluminum pitting protection is tested electrochemically using complementary procedures. The cyclic polarization procedure is best at measuring what happens as pits initiate and grow. The galvanostatic procedure is best at determining what happens as the pits repassivate. Together, a reasonable picture of the protection mechanism can be formed.

Also, a link from familiar tests and inhibitors to these unfamiliar test methods and organic

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acid inhibitors is provided. Distilled water, ethylene glycol (EG), propylene glycol (PG), ASTM Standard Specification for ASTM Reference Fluid for Coolant Tests (D 3585) in EG and PG, and commercial products are tested as benchmarks.

Experimental

Test Methods

Coolants are tested for RA (reserve alkalinity) using ASTM Standard Test Method for Reserve Alkalinity of Engine Coolants and Antirusts (D 1121), general corrosion of coupled and uncoupled metals using a modified D 1384, and aluminum pitting corrosion using FORD Laboratory Test Method BL5-1 "A Rapid Method to Predict the Effectiveness of Inhibited Coolants in Aluminum Heat Exchangers," a galvanostatic method, and cyclic polarization electrochemical methods. These tests are described separately.

RA is measured by titration of 10 mL of coolant in a 10 volume% solution with 0.1 N hydrochloric acid (HCl). Two endpoints are chosen, the D 1121 standard endpoint of pH 5.5 and a lower endpoint at pH 4.5. The intent of the RA measurement is to provide an indication of the buffer to maintain effective pH control of corrosion. Therefore, the titration must go through the buffer region of the organic acids. However, organic acids buffer below a pH 5 [6]. pH 4.5 is a compromise between titrating to even lower pH and a titrating to a pH where corrosion is still under control.

The modified D 1384 test efficiently connects typical coolant testing (coupled metal coupons) with literature references (isolated or uncoupled metal coupons). Four beakers in a 2 by 2 array contain a combination of solder (Sn30A or Modine) and coupon coupling (specimens either galvanically coupled or not). Thus the four beakers are: Sn30A with coupled metals, Modine with coupled metals, Sn30A with no coupling of metals, and Modine with no coupling of metals. Teflon spacers are used between metal specimens in the uncoupled bundles. Duplication is insured by the statistical design. Otherwise, test conditions are the same as for D 1384, 33 volume% coolant diluted with corrosive water (100 ppm of chloride (Cl^-), sulfate ($SO_4^=$), and bicarbonate (HCO_3^-)) at 88°C for 2 weeks. General corrosion is measured by weight loss.

The BL5-1 test is performed by polarizing a piece of Al 3003H at 100 $\mu A/cm^2$ for 20 min in 25 vol% coolant diluted with corrosive water to give 100 ppm each of Cl^-, $SO_4^=$, and HCO_3^-. The nonsteady state conditions of the test are important in evaluating the rate of inhibitor action. The test is run in duplicate. Two potentials relate to the tendency of aluminum to undergo pitting corrosion. The first potential, E_{max}, is a fair measure of the likelihood for the protective aluminum oxide (Al_2O_3) coating to break down. The second potential, E_{min}, is a very good measure of the likelihood for the oxide to heal. All voltages are measured against a saturated silver/silver chloride (Ag/AgCl) electrode.

The same solution and cell arrangement are used for cyclic polarization. A voltage scan is begun at -1.0 V and raised at the rate of 3 mV/s to a potential of 2.4 V. The scan is reversed, reducing the potential back to -1 V at the rate of 3 mV/s. Three potentials and a current density measurement are obtained. The first potential, E_c, is an excellent measure of the natural or "corrosion" potential of the aluminum in solution. The second potential, E_b, is an excellent measure of the "break" potential which Al_2O_3 breaks down. The third potential, E_r, is an approximate measure of the "repassivation" potential below which Al_2O_3 is again stable. The maximum current density, J_{max}, obtained during the scan indicates the rate of aluminum weight loss due to localized corrosion.

E_b from cyclic polarization and E_{max} from BL5-1 testing are measures of the same phenomena. However, E_b is obtained under assumed steady-state conditions and is considered a better measure of the "break" potential. E_{min} and E_r are nominally measures of the same phenomena.

However, E_{min}, is more sensitive to inhibitors and other coolant conditions because it is not affected by the time the sample undergoes localized corrosion, as in E_r. In either case, higher potentials represent decreased aluminum pitting.

Coolant Blending

Liquid base (either sodium hydroxide (NaOH, 50%) or potassium hydroxide (KOH, 45%)) equal to 95% of the desired total amount was added to 90% of the required amount of PG. The choice of NaOH or KOH depended on solubility, potassium salts being more soluble. The desired acid was added and allowed to dissolve completely. Azoles and antifoam were added, again waiting for complete dissolution. Base (10 weight% in PG) was added to raise the pH to the desired 8.2 to 8.4 range of the concentrate. PG was added to bring the mixture up to 100%. The formulations are given in Table 1.

TABLE 1—*Composition and RA of individual acid coolands (in wt%).*

Acid in Formula	PG	Acid	TTZ	NaOH	KOH	RA @ 5.5	RA @ 4.5
LINEAR ALIPHATIC MONOACIDS							
Propionic	91.527	4.000	0.201	4.272	. . .	. . .	. . .
Butyric	92.186	4.000	0.206	3.607	. . .	. . .	. . .
Valeric	92.714	4.006	0.203	3.077	. . .	. . .	. . .
Caproic	93.087	4.001	0.203	2.709	. . .	. . .	. . .
Heptanoic	93.329	4.007	0.201	2.464	. . .	. . .	. . .
Octanoic	93.569	4.001	0.200	2.229	. . .	10.0	26.1
Nonanoic	93.777	4.002	0.200	2.021	. . .	20.4	25.4
Decanoic	93.896	4.003	0.201	1.901	. . .	22.5	23.7
Dodecanoic	94.151	4.000	0.200	1.649	. . .	. . .	. . .
OTHER ALIPHATIC MONOACIDS							
Isoheptanoic	93.275	4.050	0.200	2.475	. . .	. . .	. . .
2-Ethylhexanoic	93.617	4.001	0.200	2.183	. . .	6.4	23.3
Cyclohexane propanoic	93.667	4.000	0.200	2.133	. . .	7.8	24.5
Oleic (40% K paste)	89.793	10.003	0.204	. . .	0.000	. . .	. . .
AROMATIC AND SUBSTITUTED AROMATIC MONOACIDS							
Benzoic	93.099	4.001	0.200	2.700	. . .	3.4	17.6
m-Cl Benzoic	93.691	4.002	0.200	2.107	. . .	. . .	. . .
p-Cl Benzoic	93.695	4.000	0.200	2.105	. . .	16.0	25.9
m-NO$_2$ Benzoic	93.826	4.003	0.200	1.971	. . .	. . .	. . .
p-NO$_2$ Benzoic	93.738	4.000	0.200	2.062	. . .	. . .	. . .
Cinnamic	93.635	4.000	0.200	2.165	. . .	3.0	23.9
Hydrocinnamic	93.728	4.000	0.200	2.072	. . .	. . .	. . .
p-Cl Cinnamic	94.033	4.007	0.200	1.760	. . .	24.5	24.9
p-NO$_2$ Cinnamic	93.360	4.000	0.200	. . .	2.440	21.4	22.3
p-OH Cinnamic	93.818	4.000	0.201	1.981	. . .	. . .	. . .
LINEAR ALIPHATIC DIACIDS							
Glutaric	91.078	4.007	0.200	4.715	. . .	17.8	47.1
Itaconic	90.903	4.000	0.201	4.896	. . .	. . .	. . .
Adipic	91.484	4.005	0.200	4.311	. . .	. . .	. . .
Pimelic	91.964	4.000	0.200	3.836	. . .	17.4	43.3
Suberic	92.230	4.000	0.200	3.570	. . .	. . .	. . .
Azelaic	90.639	4.000	0.201	. . .	5.161	15.4	36.9
Sebacic	92.324	3.500	0.200	. . .	3.976	12.8	34.4
Tetradecadioic	92.114	4.000	0.200	. . .	3.686	. . .	. . .

Results

The results are discussed by inhibitor type. Reference and conventional coolants are discussed to understand the advantages and disadvantages of the organic acids.

Reference and Conventional Coolants

RA for conventional coolants is typically in the 10 to 14 range. This is due to the inorganic acid based buffer system with pKa's in the 7 to 9 range. Sodium tetraborate, for example, buffers about pH 7.5 and only about 0.5 weight% is required to provide a sufficient RA. Also, the inorganic acids remain soluble to pH's below 3.

Five reference fluids, deionized water, uninhibited EG, uninhibited PG, D 3585 in EG, and D 3585 in PG are used for benchmarking glassware weight losses (Table 2).

There are many interesting features comparing corrosion in water, EG, and PG. First, the expected higher weight loss of Modine versus Sn30A is observed in each fluid. Further, Modine and Sn30A losses are higher when coupled to copper and brass than when uncoupled. This is consistent with solder being poorly protected by the fluids and acting as a sacrificial metal to copper and brass. This galvanic corrosion effect is most noticeable in PG where copper and brass have higher weight losses when coupled to Sn30A (low corrosion) than Modine (high corrosion). In contrast, steel and aluminum losses are lower when coupled with cast iron than when uncoupled. This is consistent with cast iron acting as a cathodic protection electrode, raising the potential of steel and aluminum to a more passive range. Unfortunately, steel and aluminum are not protective of the cast iron and corrosion is high. A different kind of coupling is displayed for aluminum corrosion in PG. This effect is such that aluminum corrosion is higher when copper corrosion is higher. The aluminum and copper specimens are never coupled

TABLE 2—*Weight losses for reference coolants in modified D 1384 test.*

| Acid | Factors | | Weight Losses, mg | | | | | |
	Coupling	Solder	Cu	Solder	Brass	Steel	Cast Fe	Al
Water	coupled	Sn30A	3.3	18.5	3.4	118.5	640.6	132.7
	coupled	Modine	3.0	58.9	2.5	178.6	551.1	123.9
	uncoupled	Sn30A	3.3	5.9	2.2	479.2	553.5	155.1
	uncoupled	Modine	4.8	55.3	4.3	433.6	706.0	196.1
EG	coupled	Sn30A	2.4	54.6	2.4	158.6	440.3	34.6
	coupled	Modine	2.3	635.5	4.1	299.3	863.5	36.9
	uncoupled	Sn30A	3.0	12.6	3.2	428.0	601.7	68.5
	uncoupled	Modine	4.6	133.1	6.1	335.2	485.4	84.1
PG	coupled	Sn30A	23.5	122.6	97.8	635.4	1036.1	118.3
	coupled	Modine	2.3	1000.0	4.7	566.1	716.0	60.3
	uncoupled	Sn30A	10.2	19.9	28.7	651.8	898.2	116.3
	uncoupled	Modine	3.3	115.6	4.5	390.9	483.1	95.8
D 3585 in EG	coupled	Sn30A	−0.1	1.6	1.5	0.6	1.0	5.0
	coupled	Modine	−0.2	3.0	1.9	0.2	−0.7	6.1
	uncoupled	Sn30A	−0.7	0.2	1.2	0.1	0.3	1.7
	uncoupled	Modine	1.8	1.0	0.8	0.9	1.1	4.6
D 3585 in PG	coupled	Sn30A	2.3	3.9	1.8	−0.3	−0.3	10.6
	coupled	Modine	1.8	6.4	1.8	0.1	−0.7	13.2
	uncoupled	Sn30A	1.8	2.9	0.9	1.1	−0.1	−12.7
	uncoupled	Modine	1.9	6.2	1.4	0.0	0.4	−2.8