SAE International®

SURFACE VEHICLE INFORMATION REPORT

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(R) Coolants for Internal Combustion Engines

RATIONALE

This document has been updated to include Appendix A in the main body of the text. Minor changes have been made to clarify various parts of the document. The title has been changed from "Engine Coolants" to clarify the scope of the document. Table 3 has been expanded to include thermal properties for 50% coolant levels.

1. SCOPE

1.1 This SAE Information Report is a source of information concerning the basic properties of engine coolants which are satisfactory for use in internal combustion engines. Engine coolant concentrate (antifreeze) must provide adequate corrosion protection, lower the freezing point, and raise the boiling point of the engine coolant. For additional information on engine coolants see ASTM D 3306 and ASTM D 4985.

1.2 The values presented describe desirable basic properties. The results from laboratory tests are not conclusive, and it should be recognized that the final selection of satisfactory coolants can be proven only after a series of performance tests in vehicles.

1.3 The document describes in general the necessary maintenance procedures for all engine coolants to insure proper performance as well as special requirements for coolants for heavy-duty engines.

1.4 This document does not cover maintenance of engine cooling system component parts.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
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2.1.1 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

ASTM D 1119	Standard Test Method for Ash Content of Engine Coolants and Antirusts
ASTM D 1120	Standard Test Method for Boiling Point of Engine Coolants
ASTM D 1121	Standard Test Method for Reserve Alkalinity of Engine Antifreeze, Antirusts, and Coolants
ASTM D 1122	Standard Test Method for Specific Gravity of Engine Coolants by the Hydrometer
ASTM D 1177	Standard Test Method for Freezing Point of Aqueous Engine Coolant Solution
ASTM D 1287	Standard Test Method for pH of Engine Antifreezes, Antirusts, and Coolants
ASTM D 1384	Standard Method for Corrosion Test for Engine Coolants in Glassware
ASTM D 1881	Standard Test Method for Foaming Tendencies of Engine Coolants in Glassware
ASTM D 1882	Standard Test Method for Effect of Cooling System Chemical Solutions on Organic Finishes for Automotive Vehicles
ASTM D 2570	Test Method for Simulated Service Corrosion Testing of Engine Coolants
ASTM D 2758	Test Method for Engine Coolants by Engine Dynamometer
ASTM D 2809	Test Method for Cavitation Erosion-Corrosion Characteristics of Aluminum Pumps with Engine Coolants
ASTM D 2847	Practice for Testing Engine Coolants in Car and Light Truck Service
ASTM D 3306	Specification for Ethylene Glycol Base Engine Coolant
ASTM D 3321	Standard Practice for Use of the Refractometer for Determining the Freezing Point of Aqueous Engine Coolants
ASTM D 4340	Test Method for Corrosion of Cast Aluminum Alloys in Engine Coolants Under Heat-Transfer Conditions
ASTM D 4985	Standard Specification for Low Silicate, Ethylene Glycol Base Engine Coolant Concentrate for Heavy Duty Engines, Requiring an Initial Charge of Supplemental Coolant Additive (SCA)
ASTM D 5931	Test Method for Density and Relative Density of Engine Coolant Concentrates and Aqueous Engine Coolants by Digital Density Meter
ASTM D 6208	Standard Test Method for Repassivation Potential of Aluminum and Its Alloys by Galvanostatic Measurement
ASTM D 6660	Standard Test Method for Freezing Point of Aqueous Ethylene Glycol Base Engine Coolants by Automatic Phase Transition Method

3. TYPES OF COOLANTS

3.1 Water

Water has been the most commonly used constituent of engine coolants for internal combustion engines because it has the ability to transfer heat and can be readily obtained. Some properties of water, such as its boiling point and freezing point, limit its usefulness when used alone as a coolant. The natural corrosive action of water on metals is definitely undesirable. Some natural water impurities, such as sulfates, chlorides, and bicarbonates, can increase corrosion. Others, such as calcium and magnesium carbonate, reduce heat transfer by the formation of scale, particularly at hot spots. They can also contribute to radiator clogging if excessive additions of hard water are made to replenish coolant losses.

Clean potable water, low in chloride, sulfate, and hardness is generally acceptable. Brackish or undrinkable water should not be used. Softened, deionized, or distilled water is ideal to dilute engine coolant concentrate. With properly inhibited coolant concentrate, water meeting the requirements outlined in Table 1 is acceptable. Water impurities exceeding these levels can cause excessive scale, sludge deposits, and increased corrosion. These impurities are measured in parts per million (PPM) on a mass basis.

TABLE 1 - WATER QUALITY

Property	Requirement
Total Solids, max.	340 ppm
Total Hardness, max.	170 ppm
Chloride (as NaCl), max.	40 ppm
Sulfate (as Na_2SO_4), max.	100 ppm
Acidity range	5.5 to 9.0 pH

When water freezes to form ice, it expands approximately 9% in volume. If water is allowed to freeze inside the cooling system, the resultant pressure can cause serious damage. In order to prevent coolant freeze damage, coolant concentrate (antifreeze) must be added to the water.

Water alone or water with inhibitors is not normally recommended as an engine coolant. The boiling point increase, provided by a 50% glycol solution, is required to maintain the design cooling index of the cooling system.

3.2 Coolant Concentrate (Antifreeze)

3.2.1 Water containing the proper amount of coolant concentrate (antifreeze) will prevent freeze-cracking damage and can be circulated freely in the cooling system at temperatures well below the freezing point of water alone. There are many requirements for an acceptable coolant concentrate (antifreeze). The most essential of these are:

3.2.1.1 The ability to protect cooling system metals from corrosion or deposits.

3.2.1.2 Minimum loss of heat transfer capability.

3.2.1.3 No deleterious effect on nonmetallic cooling system components.

3.2.1.4 Thermal stability.

3.2.1.5 The ability to lower the freezing point of the engine coolant to the lowest winter operating temperatures likely to be encountered.

3.2.1.6 The ability to raise the boiling point.

3.2.1.7 Little or no odor.

3.2.1.8 Minimum effect on vehicle finishes.

3.2.1.9 An acceptable viscosity at low temperatures.

3.2.1.10 Low coefficient of expansion.

3.2.1.11 Effective for at least one year of service.

3.2.1.12 Easily checked concentration.

In addition, low toxicity, suitable boiling point characteristics, low foaming and evaporative losses, and nonflammability are desirable. No one chemical meets each of these requirements to the fullest. However, there are materials which represent satisfactory compromises.

3.2.2 Glycol-Base Coolants

The most commonly used antifreeze material is ethylene glycol. A typical ethylene glycol-base antifreeze (coolant concentrate) will contain 95% minimum antifreeze grade ethylene glycol, corrosion inhibitors, up to 5% total water to dissolve additives, a dye, and an antifoam agent. Occasionally up to 10% of other glycols such as diethylene glycol and propylene glycol are included.

Propylene gylcol-base coolants are also used. Propylene glycol-base coolants have been approved by some automobile manufacturers and by most heavy-duty truck manufacturers in the United States. Propylene glycol-base coolants provide equivalent cooling system performance compared to ethylene glycol-base coolants, and have the advantage of having considerably reduced toxicity compared to ethylene glycol-base coolants. A typical propylene glycol-base antifreeze (coolant concentrate) will contain 94% minimum propylene glycol, corrosion inhibitors, up to 5% total water, a dye, and an antifoam agent. Occasionally up to 1% of dipropylene glycol is included. No other glycols are permitted.

Propylene glycol is nearly as effective a freeze depressant as ethylene glycol and is less toxic. However, because its specific gravity is very close to that of water, it is not possible to obtain a satisfactory field check for concentration by hydrometer. A simple hand-held refractometer, calibrated to read the freezing point of propylene glycol, is appropriate for this purpose. A dip-and-read test strip is also appropriate.

When compared to water alone, coolant solutions of glycol in water have higher boiling points, lower freezing points, and slightly lower heat transfer characteristics. See Tables 2 and 3.

TABLE 2 - BOILING AND FREEZING POINTS AT ATMOSPHERIC PRESSURE

Volume % Antifreeze	Ethylene Glycol Base Freezing Point °C	Ethylene Glycol Base Freezing Point °F	Ethylene Glycol Base Boiling Point °C	Ethylene Glycol Base Boiling Point °F	Propylene Glycol Base Freezing Point °C	Propylene Glycol Base Freezing Point °F	Propylene Glycol Base Boiling Point °C	Propylene Glycol Base Boiling Point °F
40	–24	–12	106	222	–21	–6	104	219
50	–37	–34	108	226	–33	–27	106	222
60	–52	–62	111	232	–49	–56	109	228
70	–64	–84	114	238	–61	–78	112	234

TABLE 3 - HEAT TRANSFER CHARACTERISTICS AT 99 °C (210 °F)

Volume % Antifreeze	Ethylene Glycol Base Viscosity	Ethylene Glycol Base Specific Heat	Ethylene Glycol Base Thermal Cond.	Propylene Glycol Base Viscosity	Propylene Glycol Base Specific Heat	Propylene Glycol Base Thermal Cond.
0	0.29 cP	1.01 Btu/lb/°F 4.22 kJ/kg/°C	0.39 Btu/h/ft^2/°F/ft 0.67 W/m/°C	0.29 cP	1.01 Btu/lb/°F 4.22 kJ/kg/°C	0.39 Btu/h/ft^2/°F/ft 0.67 W/m/°C
40	0.59 cP	0.90 Btu/lb/°F 3.76 kJ/kg/°C	0.26 Btu/h/ft^2/°F/ft 0.45 W/m/°C	0.62 cP	0.95 Btu/lb/°F 3.98 kJ/kg/°C	0.26 Btu/h/ft^2/°F/ft 0.45 W/m/°C
50	0.70 cP	0.88 Btu/lb/°F 3.70 kJ/kg/°C	0.23 Btu/h/ft^2/°F/ft 0.39 W/m/°C	0.75 cP	0.92 Btu/lb/°F 3.84 kJ/kg/°C	0.21 Btu/h/ft^2/°F/ft 0.37 W/m/°C
60	0.81 cP	0.83 Btu/lb/°F 3.47 kJ/kg/°C	0.21 Btu/h/ft^2/°F/ft 0.36 W/m/°C	0.95 cP	0.88 Btu/lb/°F 3.68 kJ/kg/°C	0.19 Btu/h/ft^2/°F/ft 0.33 W/m/°C

Note that the boiling point of these coolant mixtures is increased further by causing the cooling system to become pressurized. This is accomplished by using a cooling system pressure cap. See Table 10.

Manufacturers fill the cooling systems of vehicles at the factory year-round and across the country with approximately a 50% concentration of glycol-base antifreeze coolant. The higher boiling points of glycol/water coolant solutions have been found to be beneficial for hot weather operation and in high altitude areas. Glycol-base coolant solutions should be used with thermostats having opening temperatures of 82 °C (180 °F) or higher. When a glycol-base coolant is used, it is recommended that a 50 to 70% concentration be maintained year-round to provide adequate corrosion protection and a sufficiently high boiling point for automobiles and light trucks. 40 to 60% is recommended for heavy-duty engines. Concentrations over 70% result in a loss in freezing protection and heat transfer and an increase in viscosity at low temperature. In heavy-duty engines using SCA's (Supplemental Coolant Additives), glycol concentrations over 60% will contribute to inhibitor precipitation.

The use of coolant concentrate without dilution as described above is not recommended. Most coolant concentrates have a freeze point of approximately –18 °C (0 °F). Also, the heat transfer properties are adversely affected.

3.2.3 Pre-diluted Glycol Coolants

Glycol-based coolants, already pre-diluted with deionized water, have been made commercially available for user convenience and for users in areas with poor quality tap water. These products should be used, as supplied, without further dilution with water.

3.2.4 Alcohol Base Coolants

Alcohol base coolants are now obsolete.

3.2.5 Other Antifreeze Coolants

Various other chemicals are used as antifreeze coolants in special applications.

3.2.5.1 An ethylene glycol, water and glycol ether premixed combination is sometimes used for arctic service. This type of coolant is suitable for service down to –68 °C (–90 °F).

3.2.5.2 Inhibited glycol ether, specifically methoxy propanol, has been used as a coolant for heavy-duty equipment. Most heavy-duty equipment manufacturers do not recommend its use because it degrades fluorocarbon-based rubber. It is not as effective a freeze depressant as ethylene glycol.

3.2.5.3 All specialty coolant products should be used with strict adherence to the engine manufacturer's and coolant manufacturer's recommendations.

3.2.6 Different types of coolants should not be mixed.

3.3 Corrosion Inhibitors

The type of corrosion inhibitor system used in a particular vehicle is generally selected by the vehicle manufacturer. The coolant is designed and developed around the properties of the cooling system. It is important to follow the vehicle manufacturer's recommendations for coolant type when adding or changing the coolant.

A listing of the more common corrosion inhibitors and their functionality is provided in Table 4 below. It must be noted that the corrosion inhibitors contained in an engine coolant are carefully selected, balanced, and optimized to protect the various metals (aluminum, brass, copper, iron, lead, and steel alloys) present in an engine cooling system from corrosion. Certain corrosion inhibitors, while protecting one metal, may be ineffective or aggressive to other metals under certain conditions. For this reason, mixing coolants with different corrosion inhibitor chemistries may diminish the corrosion protection level of the coolants involved and is generally not recommended.

TABLE 4 - COMMON CORROSION INHIBITORS

Corrosion Inhibitors	Purpose/Protection
Azoles (BTZ, MBTZ, TTZ)	Copper, Brass, Solder
Borates	Iron, Buffering
Molybdate	Iron, Aluminum, Solder
Nitrate, NO_3	Aluminum (pitting), Solder
Nitrite, NO_2	Iron (cavitation)
Organic Additive Technology (Salts of Carboxylic Acids)	General Corrosion, Light Alloys, Solder, Iron (Cavitation)
Phosphate	Aluminum (Cavitation), Iron, Steel, Buffering
Silicate	Aluminum, Iron

There are 3 general types of coolant corrosion inhibitor systems: Inorganic (IAT or traditional North American), Organic (OAT), and Hybrid (HOAT).

3.3.1 Inorganic Systems

Inorganic systems had been used for many years, predominantly in North America. The corrosion inhibitors used are sodium or potassium salts of inorganic anions. Phosphate, silicate, borate and nitrate were commonly used. The anions chosen and their amounts depend on the coolant manufacturer. The formulation would usually contain an azole compound as a copper corrosion inhibitor.

This type of coolant is being replaced with OAT or HOAT types as new vehicle factory fill.

3.3.2 Organic Systems

Organic systems use salts of organic anions as corrosion inhibitors. Sodium sebacate, 2-ethyl hexanoate, azaleate and benzoate are common. Sometimes 2 or more organic anions are used in the same formulation. The formulation would also contain an azole compound as a copper corrosion inhibitor.

This type generally provides longer service life than the inorganic types. That reduces maintenance requirements and, therefore, the amount of waste coolant generated.

3.3.3 Hybrid Systems

Hybrid systems use an organic anion as the primary corrosion inhibitor. Some inorganic salts are added to enhance certain properties.

3.3.3.1 These can be divided into two general types.

The formulations of European origin usually use low levels of silicate as a major inorganic anion. The use of phosphate is generally forbidden.

The formulations of Japanese origin usually use phosphate as a major inorganic anion. The use of silicate and borate is generally forbidden.

This means that the two types of HOAT are not interchangeable. The inhibitors used in Europe and North America are not allowed by the Japanese OEM specifications and, conversely, the inhibitors used in Japanese coolants are not allowed by the European and North American OEM specifications. The vehicle manufacturer's recommendation for coolant should be followed.

3.3.3.2 These HOAT types also provide longer service life than the inorganic types. The inorganic anions can limit the service life. At least one vehicle manufacturer uses a system to replenish the inorganic material to extend the service life.

4. PROPERTIES

Properties which are considered in testing and evaluating the antifreeze coolant concentrate and its solutions are described in the following paragraphs. The ASTM test methods for measuring these properties are listed as follows:

ASTM D 1119—Standard Test Method for Ash Content of Engine Coolants and Antirusts
ASTM D 1120—Standard Test Method for Boiling Point of Engine Coolants
ASTM D 1121—Standard Test Method for Reserve Alkalinity of Engine Antifreeze, Antirusts, and Coolants
ASTM D 1122—Standard Test Method for Specific Gravity of Engine Coolants by Hydrometer
ASTM D 1177—Standard Test Method for Freezing Point of Aqueous Engine Coolant Solution
ASTM D 1287—Standard Test Method for pH of Engine Antifreezes, Antirusts, and Coolants
ASTM D 1881—Standard Test Method for Foaming Tendencies of Engine Coolants in Glassware
ASTM D 1882—Standard Test Method for Effect of Cooling System Chemical Solutions on Organic Finishes for Automotive Vehicles
ASTM D 3321—Standard Practice for Use of the Refractometer for Determining the Freezing Point of Aqueous Engine Coolants
ASTM D 5931—Standard Test Method for Density and Relative Density of Engine Coolant Concentrates and Aqueous Engine Coolants by Digital Density Meter
ASTM D 6660—Standard Test Method for Freezing Point of Aqueous Ethylene Glycol Base Engine Coolants by Automatic Phase Transition Method

4.1 Ash Content

Ash content of a coolant concentrate is the residue which remains after ignition. For most formulations, the ash content will be less than 5.0% by weight. While the ash results from the inhibitors used, it is not a measure of inhibitor concentration.

4.2 Equilibrium Boiling Point

Equilibrium boiling point indicates the temperatures at which the coolant begins to boil in a cooling system under equilibrium conditions at atmospheric pressure. The boiling point of a coolant is an important property, especially when high opening temperature thermostats are used or when the cooling system is operated at high ambient temperatures or under high heat load conditions. See Table 2 and Table A3.

4.3 Reserve Alkalinity

Reserve alkalinity is a term applied to engine coolant concentrates and antirusts to indicate the amount of alkaline inhibitors present in the product.

Reserve alkalinity is defined as the number of milliliters, to the nearest 0.1 mL, of 0.100 N hydrochloric acid required for the titration to a pH of 5.5 of a 10 mL sample of undiluted antifreeze, antirust, or coolant additive.

Mildly alkaline solutions are generally less corrosive than strongly acid or strongly alkaline solutions. Neither pH nor reserve alkalinity is a sufficient criterion to indicate the quality or level of corrosion inhibitors. Different inhibitor systems have individual optimum pH ranges. Many of the very efficient corrosion inhibitors have very little effect on the reserve alkalinity.

The reserve alkalinity is most useful as part of a qualification test to indicate that a submitted lot is similar to a previously qualified sample.

The reserve alkalinity of a used coolant is not a dependable indication of either existing effectiveness or remaining life of the solution. The measurement gives an indication of the capacity of the coolant to neutralize acids which may be present or form in the cooling system.

4.4 Specific Gravity

Specific gravity is the ratio of the mass of a given volume of liquid to the mass of an equal volume of gas-free distilled water at a specific temperature. Its measurement offers a convenient means of identifying the degree of dilution and hence the freezing point of ethylene glycol coolants. While the specific gravity for pure ethylene glycol is 1.115 at 20 °C (68 °F), the specific gravity of the coolant concentrate will be somewhat different depending upon the type and the amount of inhibitors used, on the amount of water present, and on the amount of other glycols present. Because the specific gravity of propylene glycol is similar to that of water, use of specific gravity to measure the freezing point of propylene glycol coolants is not recommended.

4.5 Freezing Point

Freezing point is defined as the temperature at which ice crystallization begins in the absence of supercooling, or the maximum temperature reached immediately after initial ice crystal formation in the case of supercooling. The ASTM D 1177 or ASTM D 6660 methods of freezing point determination should be used when freezing point accuracy is desired, as in determining the limiting values for specifications. Hydrometers, refractometers, or test strips are used in the field to determine the expected freezing point of coolants. (The hydrometers will give erroneous results for ethylene glycol-base coolants if the content of other glycols, such as diethylene glycol or propylene glycol is too high. However, many commercial refractometers also include a scale for propylene glycol.) Because of the limited accuracy of hydrometer-thermometer testers, the results should be viewed as an approximate freezing point rather than a precise measurement. Freezing points can be determined more accurately by the refractometer type field tester. (ASTM D 3321 describes the use of a refractometer for determining freezing points.) See Tables 6 and 7 for freezing points of ethylene glycol and water mixtures and Tables 8 and 9 for freezing points of propylene glycol and water mixtures.

4.6 pH

pH is a measurement of the hydrogen ion concentration and indicates whether a coolant is acidic, neutral, or alkaline. pH measurements are sometimes used for production quality control, but are not reliable indicators to predict service life. However, as the pH approaches neutral, and certainly before it drops below 7, the coolant should be replaced.

4.7 Foaming Tendency

Foaming tendency of a coolant is measured by the amount of foam generated during aeration under controlled conditions and the time required for this foam to subside. If the coolant foams excessively and the system is open, coolant losses will take place through the overflow tube of the radiator. Heat transfer properties of the coolant are also reduced due to foaming.

4.8 Organic Finishes

Organic finishes shall not be adversely affected by the coolant. This is of particular importance to the vehicle manufacturer during assembly operations and to the vehicle owner during coolant installation in the event of accidental spillage.

4.9 Color

All coolant concentrates must contain a dye as a positive visual identification that an antifreeze coolant is being used. Many colors are used for glycol-base antifreeze coolants.

4.10 Effect on Nonmetallics

The coolant solution should not accelerate failure of the radiator hose, gaskets, and nonmetallic coatings on metallic gaskets. Many immersion tests, as well as other tests, have been proposed for this evaluation. Each supplier and consumer has his favorite procedure. The final evaluation, of course, is service experience. Preliminary indications are obtained when the coolant is tested for corrosion inhibition in simulated service and engine dynamometer tests.

4.11 Storage Stability

Storage stability of the concentrate cannot be determined conclusively by accelerated tests. However, it is evident that the packaged concentrate must be stable for at least 2 years under many different climatic conditions.

5. CORROSION INHIBITION

5.1 Corrosion

If corrosion of the cooling system of an internal combustion engine is allowed to proceed without interruption, it not only shortens the life of metallic components but it also reduces the heat transfer efficiency of the cooling system. For these reasons, effective corrosion inhibition must be provided and maintained in the cooling system.

5.2 Corrosion Testing

Because of the elapsed time involved in the field testing of inhibitors and inhibited coolants, accelerated tests are used in an attempt to evaluate the effectiveness of these products. The results from accelerated tests can be indicative of quality only if the tests incorporate many of the factors which affect corrosion in the cooling system. Some of the more important factors to be included are:

5.2.1 Coolant concentration

5.2.2 Flow rate

5.2.3 Aeration

5.2.4 Temperature

5.2.5 Water quality

5.2.6 Galvanic couples and crevices

5.2.7 Corrosion products

5.2.8 Heat rejecting metal surfaces

5.3 As a test incorporates more of these factors, it more nearly simulates service performance, but it usually requires more labor and it becomes more costly. The generally accepted order of evaluation tests is:

5.3.1 Screening test (glassware corrosion test)

5.3.2 Heat rejecting aluminum test

5.3.3 Simulated service test

5.3.4 Dynamometer test

5.3.5 Field service test

5.4 Special tests are required to evaluate the performance of coolants with regard to specific forms of corrosive attack. These stepwise procedures are used to avoid the unnecessary expenditure of time and money performing long expensive tests on obviously poor coolants and to ensure that better coolants will meet service requirements by the use of more rigorous test conditions. Vehicle service tests are desirable as the final evaluation method because they most closely approximate actual use and conditions

5.4.1 Glassware Tests

A glassware test procedure can be used to evaluate all types of coolants and inhibitors. The advantages of this type of test are its simplicity, reproducibility, and brevity. For these reasons, it is used to screen a large number of samples with minimal effort.

Weighed metal specimens common to the engine cooling system are immersed in a heated, aerated test solution for the entire period of the test. Corrosion products are removed from each metal at the end of the test, and the metal weight losses determined. Corrosion inhibition is evaluated on the basis of these metal mass loss values. A material is presumed to fail the test if the mass loss of any metal is above the limit.

A typical glassware corrosion test for the evaluation of coolants is that found in ASTM D 1384.

5.4.2 Simulated Service Tests

This test concept involves the circulation of coolant, at a preselected operating temperature, in a test rig simulating an engine cooling system. Several automobile parts are used in the construction of the test rigs including a coolant pump, coolant outlet, radiator, and radiator hoses. By the use of a large reservoir, or an engine block, a volume of coolant equivalent to that in a cooling system can be used. Coolant flow rates within the normal operating range are achieved by driving the coolant pump with an electric motor. This test simulates the engine cooling system more closely than the glassware test and is more discriminating in coolant performance evaluation. Corrosion inhibition is measured from mass losses of metal specimens placed in the system and by visual examination of the components. If standard radiator hoses are used, coolant effects on the hoses can be observed. By sampling the coolant at intervals during the test, coolant concentration can be controlled and solution properties monitored. Experience has shown that they are useful development tools, but for some specimen metals, repeatability between tests may not be consistent and reproducibility among different laboratories may vary widely. The use of components of different materials, such as an aluminum reservoir versus cast iron or an aluminum radiator versus brass, can significantly affect certain metal specimen weight losses. In view of these circumstances, it is desirable to evaluate test rigs and data by running multiple tests with coolants of known service performance.

Although there are many variations in procedure, a recommended test procedure has been developed under the sponsorship of ASTM Committee D-15. This method is listed as ASTM D 2570.

5.4.3 Dynamometer Tests

Engine coolants can also be evaluated by an engine dynamometer test procedure. The advantage of this method over either the glassware test or the simulated service test is that test conditions such as load, speed, coolant temperature, and heat transfer are observed, controlled, and varied through the operation of a standard engine. The performance of the engine is monitored throughout the test to ensure the reproduction of the proper service conditions. This type of test is more significant if the radiator, pump, and engine combination is the same as that normally used in an actual vehicle.

Corrosion protection is evaluated by the determination of mass losses of metal specimens in contact with the coolant, and by the inspection of parts at the conclusion of the test. Inhibitor stability is determined from changes in pH, reserve alkalinity, and solution appearance. Various qualitative and quantitative analyses may be obtained for the inhibitors known to be present. Although this test is expensive to run, it provides more meaningful results than other laboratory results.

ASTM D 2758 describes a 700 h test in a standard passenger car engine.

5.4.4 Field Tests

The final test of any coolant is its performance in vehicles in the field. Closely controlled tests can be made under the supervision of technical personnel. General field tests can be conducted in a large number of vehicles to provide a broad service pattern. Metal specimens may be installed in the coolant stream to determine corrosion rates. The coolant can be sampled periodically to determine its chemical and physical properties. The condition of the cooling system and components should be carefully examined at the end of the test. Information should be obtained from the participants concerning their observations regarding cooling system performance. If at all possible, vehicles from different areas of the country should be utilized for the tests, which will involve a range of antifreeze coolant concentrations with a variety of local waters.

ASTM D 2847 is a standard practice for testing engine coolants in vehicle service. Metal corrosion specimens, mounted in special capsules, are installed in the coolant flow of the test vehicles. The test duration in terms of time or mileage is consistent with the recommended service life of the coolant under test.

5.4.5 Aluminum Water Pump Cavitation Tests

Cavitation erosion corrosion of water pumps constructed of aluminum can be a serious problem because of the rate at which damage may occur. This type of corrosion is usually the result of pump design and cooling system characteristics. At certain coolant velocities, low and high pressure areas develop that cause the formation of vapor bubbles which implode on the surface of the metal and cause segments of metal to be removed. The composition of the coolant has been found to have a contributing effect on cavitation erosion, and it is often necessary to evaluate coolant formulations under cavitating conditions. Many different methods have been used to induce cavitation for laboratory studies, but it is preferable to use an operating pump under controlled conditions.

Final evidence of satisfactory cavitation-erosion prevention may be confirmed by ASTM D 2809. In this procedure, test coolant is pumped through a pressurized, simulated automotive cooling system at a temperature of 112 °C (235 °F) for 100 h. The pump is driven by an electric motor at a high speed and cavitation occurs. After the test, the complete pump is examined and rated by a numerical system.

5.4.6 Aluminum Heat Rejecting Corrosion and Transport Tests

Aluminum corrosion transport deposition may occur with engines containing aluminum cylinder heads or other aluminum heat rejecting (from metal to coolant) surfaces. While the metal loss from aluminum surfaces may be relatively small and have no effect on the strength or durability of the aluminum components, the volume of corrosion products deposited in coolant passages of radiator or heater cores will reduce heat transfer and may result in plugged passages. The composition of the corrosion inhibitors in the antifreeze formulation can affect this type of corrosion.

Several test methods have been used to evaluate engine coolants for aluminum corrosion transport deposition including car tests. The accelerated laboratory tests involve circulating the test coolant in an apparatus so that the coolant is heated by an aluminum part and cooled with a copper, brass, or aluminum part. Performance is evaluated by the amount of corrosion (mass loss) from the heating aluminum part and/or the increase in mass of the cooling part. If the cooling part is a radiator or heater core, evaluation is based on loss in heat transfer or visually observing the quantity of deposits in the water passages.

Screening evaluation of coolants for corrosion of aluminum heat rejecting surfaces can be done using ASTM D 4340. This method does not evaluate the resultant transport deposition which may occur.

5.4.7 Aluminum Crevice and Pitting Corrosion

Aluminum radiators and heater cores may fail from perforation due to pitting and crevice corrosion. The design of the unit may involve gasketed tank to header joints which create adjacent crevice areas at the gasket to header interface. These locations require specific inhibition from pitting corrosion. Several test methods may be used to evaluate coolant inhibitor performance. Accelerated laboratory electrochemical tests can indicate the tendency for pitting corrosion which should correlate with actual service performance or simulated service tests. ASTM D 6208 is an example of such a test. An aluminum radiator can be used in a simulated service test such as ASTM D 2570. At test termination, the subject radiator must be disassembled and sectioned for a comprehensive inspection for corrosion sites. Variations of this method involving extended test period, increased coolant temperature, diluted coolant, and more corrosive water may be employed to increase test severity. Extended vehicle tests provide the most conclusive method results but require a longer test period with increased variables, reduced control and increased cost.

6. MAINTENANCE OF ENGINE COOLANTS

Satisfactory performance of the engine coolant depends upon the use of the proper coolant, changing the coolant at prescribed intervals and maintenance of coolant volume, coolant concentration, cleanliness, and tightness of the engine cooling system.

6.1 Coolant Volume

It is important that the engine coolant be maintained at the level specified by the vehicle manufacturer. The proper level for most modern cars is shown in the coolant recovery tank or container. This container collects the overflow coolant when the coolant expands and from which the coolant is drawn back into the radiator when the coolant cools. The level marks are usually labeled cold and hot or full cold and full hot because the volume present is related to the temperature of the coolant. In cars that do not have a coolant recovery system, the level may be shown by a mark on the tank of the radiator. Periodic inspection of the coolant level in the recovery tank should be made to ensure that the coolant is at the proper level. For heavy-duty engines, the coolant level should be checked as directed by the vehicle manufacturer. Many heavy-duty vehicles do not use coolant recovery tanks.

If overheating should occur even though the coolant level is sufficient, the cooling system should be allowed to cool before opening any closures to check the system contents. A check should be made to see if air is trapped in the radiator, particularly after the system has been drained and filled and the air may not have been released. When it is necessary to add coolant, a 50/50 mixture of a glycol coolant concentrate and water should be added. Caution see 6.3.

Loss of coolant may usually be attributed to one or more of the following:

6.1.1 Overflowing, After-Boiling, and Overheating

Overflowing is the loss of coolant during normal driving. The loss occurs because the system has been filled above the manufacturer's recommended level when the system was cold. As the coolant temperature increases, the coolant expands and is forced out of the coolant recovery tank, or radiator in the case of older model cars, and heavy-duty vehicles without recovery tanks. Proper coolant level minimizes the possibility for loss of coolant through overflow.

After-boiling is the boiling of the coolant in the engine block after the engine is stopped when the vehicle has been driven at high speeds or has been under a heavy load. The residual heat in the engine causes the coolant temperature to rise above its boiling point, because the coolant is no longer being circulated and cooled.

Overheating may be defined as a condition where the coolant temperature exceeds the normal operating range as indicated by the coolant warning light or temperature gauge. When this occurs, it is best to reduce the load on the cooling system by shifting the transmission to neutral and turning off the air conditioner. It also helps to reduce coolant temperature by increasing the engine idle speed for 2 or 3 min in vehicles with mechanical fans (to increase fan cooling and coolant pump output) and to turn on or increase the heater to maximum temperature and fan speed. The heater core will function as a small radiator. Several factors can contribute such as a faulty thermostat or cooling system pressure cap, fan belt malfunction, radiator tube plugging, or the accumulation of corrosion deposits or scale in the radiator that reduce heat transfer. In addition, the use of coolant solutions with lower boiling points than those provided by the recommended glycol water mixture can also be a factor in after-boiling or overheating. After-boiling or overheating can be minimized by ensuring that components are operating properly and that a satisfactory coolant is used and maintained.

6.1.2 Coolant Leakage

Leaks usually occur because of loose fitting parts or through cracks or pin holes caused by corrosion or deterioration of materials. Susceptible locations are hose connections, gasketed parts such as the cylinder head to thermostat, core hole plugs, pump seals, and radiator or heater core assemblies. When a leak occurs, the source should be identified and the leakage rate determined before attempting to stop the leak. The leak often can be corrected by tightening a clamp or bolt, but in many cases it may be necessary to replace the component part. Minor leaks may be sealed through the use of commercial stop-leak materials, but one is cautioned that this is <u>never a substitute</u> for mechanical repairs. Furthermore, overuse of stop-leak products contributes to the solids in the cooling system, which can affect heat transfer and tube plugging. Most light-duty vehicle original equipment manufacturers and heavy-duty engine builders recommend that stop-leak not be used.

6.1.3 Exhaust Gas Leakage, Air Leakage, and Foaming

Air can be drawn into the coolant at loose hose connections or through the water pump seal. Exhaust gas leakage into the coolant occurs between the combustion chamber and the water jacket, usually because of a loose gasket or a cracked casting. Gases that enter the system become entrained in the coolant, occupying space and increasing the volume of the coolant. Gases can also rise to high points in the system as foam. Antifoam agents are usually added to the coolant concentrate to reduce the formation of foam, but these agents may be dissipated rather rapidly.

The increased volume occupied by the gas-liquid mixture can cause coolant losses during thermal expansion. In addition, if antifoam agents in the antifreeze are depleted, and the deaeration system for the radiator is inadequate to separate the gas from liquid before reentering the pump, then mass flow through the engine and radiator is reduced. This raises the ΔT across the engine, and the higher engine out temperature will result in overheating as indicated by the temperature gage and possibly an alarm.

Continued aeration of the system accelerates depletion of coolant inhibitors and can contribute to increased corrosion and/or erosion in the system. Air leakage to the coolant can be minimized by maintaining a proper coolant level and by good maintenance to ensure satisfactory operation of parts and tight joints.

Exhaust gases are normally acidic and leakage into the cooling system contributes not only to foaming and overheating but also to inhibitor depletion, accelerated corrosion, and a more rapid breakdown of glycol solutions. Any evidence of leakage requires immediate mechanical repair.

6.2 Antifreeze Coolant Concentration

Essentially all liquid cooled engines are designed for aqueous glycol coolant systems. Since water alone is inadequate (see 3.1 and 3.2), a coolant concentrate (antifreeze) is usually added. Most automobile manufacturers and heavy-duty manufacturers fill the cooling system with approximately a 50% ethylene glycol-base coolant. This concentration will supply more freeze protection than is required for most climates, but is recommended to ensure adequate concentration of corrosion inhibitors. Maximum freeze point depression with ethylene glycol is obtained with 68% concentrate. To achieve higher boiling points for use at higher ambient temperatures, under heavy loads, or at higher altitudes, a maximum of 70% ethylene glycol-base coolant can be used, except for heavy-duty engines using SCA's, where glycol concentrations over 60% will contribute to undesirable inhibitor precipitation. When replenishing the cooling system, the proper proportions of water and glycol should be added to maintain the desired ratio.

Should the coolant freeze, the automobile should not be operated until normal circulation is restored by a suitable thawing operation. The coolant can form a slush which will clog the radiator, resulting in overheating, loss of coolant, and consequent damage to the engine such as cylinder head cracking at the combustion chamber.

6.3 Caution

If the coolant becomes overheated, the entire coolant solution must be cooled down before opening the radiator cap. If the cooling system is opened, the pressure will be reduced to atmospheric and coolant above its boiling point at this lower pressure will flash to a vapor and force out hot coolant. The risk of personal injury is very great.

6.4 Coolant Replacement

The vehicle manufacturer's and/or coolant manufacturer's directions for periodic changes should be followed. Periodic replacement of coolant solutions is required because the solutions may become corrosive due to chemical reaction, contamination, or inhibitor depletion. In heavy-duty systems using SCA’s, the total dissolved solids can become too high.

6.5 Coolant Selection

An engine coolant should be selected with care to ensure adequate corrosion protection. Only those products conforming to recognized SAE and/or ASTM standards for the engine system involved should be used.

Automobile and light truck applications will require ASTM D 3306 glycol type coolant offering protection of aluminum heat rejecting surfaces. This is critical in engine systems which contain heat rejecting aluminum surfaces such as heads or blocks.

Heavy-duty engine applications will require ASTM D 4985 glycol coolant concentrates and periodic additions of supplemental coolant additives (SCA’s).

6.6 Extension of Coolant Use and Coolant Recycling

Due to the high cost and shortages of ethylene glycol in 1988 and increasing environmental awareness, extending the useful life of coolants in light-duty applications and also recycling of spent coolant from both light- and heavy-duty engines has become attractive. (The life of coolants used in heavy-duty engines has historically been extended by use of periodic SCA additions and on-board coolant filtration. See Section 7.3.)

The only processes currently approved by light- and heavy-duty OEM’s are those that recover pure glycol (of antifreeze grade) from the spent coolant. This glycol is then used to blend essentially new antifreeze.

Other processes (such as off-board filters coupled with SCA additions) for extending coolant life for coolants used in light-duty applications have been commercialized.

6.7 Cleaning

A properly inhibited, normally functioning cooling system should not require chemical cleaning. Cooling systems should be cleaned only when indicated by the appearance of rust or sediment or persistent overheating. The type of cleaner to be used is indicated by the condition of the system and the types of metal components in the system.

Conventional cooling systems, with brass, copper, and cast iron used in major components, can be treated with available flush-type cleaners for oily deposits and acid-type cleaners or chelators for rust deposits. Cooling systems utilizing aluminum components should use only those cleaners specified as safe for aluminum. In general, these cleaners are neither strong acids nor strong alkalies.

Residual cleaning components (including neutralizers) should be flushed from the system because some cleaners, if left in the cooling system, may attack components and shorten the service life of newly installed antifreeze coolants or supplemental additives.

Clogged radiators will not respond to chemical treatment and will require repair or replacement.

7. SPECIAL COOLANT CONSIDERATIONS FOR HEAVY-DUTY ENGINES

7.1 Automobile Versus Heavy-Duty Engine Service

The unique needs of the heavy-duty system are both a function of the system design and the demands made upon the system. These differences can be summed up as:

7.1.1 Life

7.1.2 Load

7.1.3 Usage

7.1.4 Wet sleeves

7.2 Table 5 contrasts in more detail the differences between automobile and heavy-duty engine service.

TABLE 5 - DIFFERENCES BETWEEN LIGHT-DUTY VEHICLE, ON HIGHWAY HEAVY-DUTY, AND OFF HIGHWAY HEAVY-DUTY ENGINE SERVICES

	Light-Duty Vehicle	On Highway Heavy-Duty	Off Highway Heavy-Duty
Expected life to first overhaul	160 000 km (100 000 miles)	800 000 km (500 000 miles)or 15 000 h	25,000 h
Total expected life	240 000 km (150 000 miles)	1 160 000 km (1 000 000 miles) or >30 000 h	75,000 h
Vehicle Use rate	24 000 km/year (15 000 miles/year)	24 000 km/month (15 000 miles/month) or 500 h/month	600 h/month
Load factor	less than 30%	about 70%	75%
Gross Vehicle Weight per HP (watt)	18 kg/kW (30 lb/HP)	120 kg/kW (200 lb/HP)	240 kg/kW(400 lb/HP)
Uses wet sleeve cylinders	very few	most	all

7.3 Supplemental Coolant Additives and Their Economics

Heavy-duty engine builders began using supplemental coolant additives (SCA's) in the 1950's to control the pitting of cast iron cylinder liners. Since that time, SCA's have proven effective for long-term protection of the heavy-duty engine cooling system. At this time, all heavy-duty engine manufacturers in the United States recommend the use of some type of SCA.

The SCA may be initially added to the cooling system to make up for some deficiencies of the coolant concentrate (antifreeze) additive package in protecting heavy-duty engine cooling systems, such as cast iron cylinder liner cavitation corrosion protection and hot surface scaling protection. However, heavy-duty engine manufacturers are now recommending the use of fully formulated coolants which do not require an initial charge of SCA's. The SCA is also added to the cooling system at the time of each oil change to replace additives lost because of dilution and depletion. Historically, coolant concentrate (antifreeze) additive packages have been formulated to meet the needs of the automobile cooling system; consequently, most coolant concentrates are not optimized to meet the needs of a heavy-duty engine cooling system. Experience has shown that without the use of an SCA, liner pitting can become a problem in as little as 48 000 km (30 000 miles).

Coolant concentrate (antifreeze) for heavy-duty engines can be formulated to overcome the previous deficiencies, but it will still deteriorate over the long term under the conditions of use. For an automobile, several years of service may be expected before the service life of coolant concentrate (antifreeze) is accumulated, but in many line haul truck fleet operations the same coolant service life may be reached in just one month. To maintain an adequate level of additive in the system, the coolant could be changed on a monthly basis, but it is far less expensive to add an SCA to keep the protection at adequate levels and extend coolant life.

Actual savings of using SCA's versus frequently changing the coolant can be quickly calculated by considering the approximate time to change a coolant service filter versus antifreeze coolant (5-10 min versus 30-60 min). Other factors needed for the calculation are labor rate, volume of coolant required, coolant cost, and coolant service filter cost.

8. COOLANT FOR A HEAVY-DUTY ENGINE CONSISTS OF:

8.1 Water

8.2 Coolant Concentrate (antifreeze)

8.3 Supplemental Coolant Additive (SCA)

8.4 If freeze and boil over protection are not required, the coolant may consist of simply water and SCA

8.4.1 Water

Water quality affects the efficiency of coolant additives and components. When untreated, all water is corrosive. Water with extremely high mineral content or corrosive chemicals is unfit for cooling system use. The local water department or the Department of Agriculture should be contacted, or a water sample should be submitted for analysis if there is any question about water quality. See 3.1, Table 1, for specific water quality guidelines.

8.4.2 Coolant Concentrate (Antifreeze)

Ethylene or propylene glycol-base coolant concentrate (antifreeze) is used for freeze and boil over protection. Concentration should be maintained between 40 and 60%, depending on operating environment. A low silicate product meeting ASTM D 4985 should be used.

8.4.3 Supplemental Coolant Additives

Supplemental coolant additives are used for protection (against deposits, corrosion, and pitting) not provided by the chemicals in the coolant concentrate (antifreeze). SCA's also extend the life of coolant by adding to and replenishing additives that deplete during normal operation. SCA's, however, do not affect the freeze or boil over protection of the coolant.

While the coolant life for heavy-duty engines can be extended with the use of SCA's, a coolant cannot be used indefinitely. It is recommended that coolant not be used for more than 2 years. The reason is that coolant gradually becomes saturated with spent additives. Additive dropout can take place, which, especially without a coolant filter, can foul the cooling system. In addition, the additive package can become imbalanced over long periods of time thus degrading cooling system protection. Other factors that limit coolant life are oil, dirt, combustion gas contamination, and thermal breakdown of the coolant itself.

9. COOLANT MAINTENANCE RECOMMENDATIONS FOR HEAVY-DUTY ENGINES

9.1 If any of the following recommendations differ from the engine or vehicle manufacturer's recommendations, follow the engine or vehicle manufacturer's recommendations.

9.2 Use coolant concentrate meeting ASTM D 4985.

9.3 Drain and flush the cooling system annually.

9.4 Follow the engine or vehicle manufacturer's recommendations for SCA precharging of the cooling system after draining and flushing.