SURFACE VEHICLE RECOMMENDED PRACTICE

J1436™ JUN2023

Issued 1983-09
Revised 2023-06

Superseding J1436 JUL2018

Requirements for Engine Cooling System Filling, Deaeration, and Drawdown Tests

RATIONALE

SAE Five-Year Review and requirements clarification.

1. SCOPE

This SAE Recommended Practice is applicable to all engine cooling systems used in (1) heavy-duty vehicles, industrial applications, and (2) automotive applications.

There are two categories of coolant reservoir tanks covered in the document:

a. Pressurized tanks

b. Unpressurized tanks

1.1 Purpose

The purpose of this document is to list the requirements which are in general use for filling, deaeration, expansion volume, and drawdown of engine cooling systems for heavy-duty, industrial, and automotive applications. Due to the differences in heavy duty and automotive cooling systems, they are dealt with in separate sections of this recommended practice. In the case of heavy duty, these procedures apply to both the main jacket water pump and separate circuit water pumps. The material presented in this document is a recommended practice only and does not constitute a SAE standard.

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.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J151 Pressure Relief for Cooling System

SAE J164 Cooling System Metallic Caps and Filler Necks

SAE J1004 Glossary of Engine Cooling System Terms

SAE J3096 Cooling System Non-Metallic Caps and Filler Necks - Threaded Construction

3. APPLICATIONS

3.1 Heavy Duty and Industrial Equipment

3.1.1 Leveling

Before starting any test, the heavy duty vehicle or equipment shall be in a plane parallel to the horizontal level.

3.1.2 Filling

With the engine off, thermostats closed, a completely drained system (including heater, other accessories, and their lines) must be filled with cold coolant (20 °C) at the manufacturer's recommended fill rate (for example: 19 L/min ± 2 L/min [5 gpm ± 0.5 gpm] or 11 L/min ± 1 L/min [3 gpm ± 0.3 gpm]) with hose until the filler neck overflows when system is equipped with reservoir tank; when the system is equipped with surge tank, fill it at the highest target cold fill level and follow the manufacturer's instructions on venting the engine and accessories.

Close shutters or block the airflow to the radiator with cardboard segments and run the engine at approximately rated speed without pressure cap until the thermostats open. The opening of the thermostats may be detected by observing the flow in the radiator inlet line sight glass, by noting a sudden rise in inlet line or top-tank temperature, or by noting when the coolant temperature exceeds the thermostat rating by 3 °C (5 °F). Continue running the engine for 5 minutes, and then stop the engine and measure the amount of coolant required to refill the system to the 100% full point, which is defined to be at the bottom of the filler-neck extension (cold-fill level) or to the recommended cold-fill "Full" mark if there is no filler neck extension.

The quantity of coolant added shall not exceed 10% of the total system capacity defined in 3.1.6. An engine manufacturer may grant permission in a specific case to exceed 10% of total system capacity, but in no case shall the quantity of coolant added exceed the system drawdown rating, defined in 3.1.5.

The test applies in general to systems of up to 95 L (100 quart) capacity, although much larger systems in heavy duty applications will have similar requirements and test methods. However, unique fill rates may be required in special instances and will be specified by the engine manufacturer. If the system fills slower than desired, (<11 L/min), the manufacturer may require a low coolant warning sensor to detect poor initial fill or lack of top off. Most manufacturers now require a low coolant sensor regardless of fill performance. For systems over 95 L (100 quart) capacity, the engine manufacturer may call for a higher fill rate in order to keep the total fill time to a reasonable period.

In addition, in certain instances where air entrapment in the fill line (shunt line) may be suspected, the engine manufacturer may call for a bucket fill test. In larger systems, particularly those with remotely mounted heaters, manual air-bleed vent valves may be required.

3.1.3 Expansion Volume

Coolant system filling may be done at the radiator top tank or through a remotely located tank such as an overflow tank or a surge tank. Radiator top tanks and surge tanks, being pressurized, and which include the expansion volume and the radiator pressure cap, will have a filler neck extension to limit the "cold full" level to avoid filling the expansion volume that is needed to accommodate the coolant volume change as it reaches operating temperature. The filler neck extension will incorporate a breather hole above the "hot full" level to allow air to escape while filling, and the size of the hole will depend on the required fill rate. Overflow tanks, being unpressurized, do not include filler neck extensions and require completely filling both the radiator top tank and the overflow tank up to the "cold full" level. As discussed above, expansion volume in the overflow tank must be provided to accommodate the coolant volume change as it reaches operating temperature.

The expansion volume needed above the “cold full” level will be dependent upon several parameters including the water-glycol ratio, the maximum allowable coolant temperature, the afterboil effect present at the top tank and the temperature of the coolant when filled cold. For example, if a system is filled cold at 21 °C (70 °F) with a 50% water-glycol mixture (based on volume), a 6% expansion volume above the “cold full” level accommodates a 110 °C (230 °F) maximum coolant temperature and an extra 1% expansion space beyond that will accommodate an additional 10 °C (18 °F) afterboil effect. Each manufacturer should account for coolant expansion volume according to their design requirements. It should be noted that excess expansion volume may preclude the system from pressurizing to the intended level, which could result in unintended boiling.

In some cases, a “full level” and “add level” may be marked on a pressurized tank using a sight glass or on the surface of a non-metallic remote tank. A typical volume between these levels is in the range of 4 to 6% of system volume. So, the total combined volume between “add level” and filler neck level may vary between 8 to 16%, depending on manufacturer’s recommendations. Again, the more volume added for these volumes, the more challenging it is to pressurize the system and the more space required.

Most systems today will also include a low coolant level sensor, and it may be located in an unpressurized or pressurized tank, or in the coolant line upstream of the pump. The location of the sensor will often be synonymous with the “add level” in a pressurized tank and serve as the only indication of low coolant level. Independent of its location relative to the “add level,” the sensor location is generally located ~16% of system volume below the “full level.” The low coolant level sensor should always be located above the system’s drawdown limit.

3.1.4 Deaeration

Engine manufacturers require tests of the cooling system deaeration capability to remove gases from the coolant during operation. These gases may originate from air entrainment during filling, from vortex formation at the fill line (shunt line) connection when a vehicle is not operating on a level surface, from centrifugal forces in a prolonged turn, or from combustion gases leaking across cylinder-head seals.

Also, deaeration capability is a measurement of the radiator inlet tank (or top tank) to remove air to the free surface of the coolant at a specified rate without passing enough air through the radiator assembly and into the pump inlet to reduce pump performance by a specified amount (e.g., 3% of the system flow rate without losing 10% in pump pressure rise with the coolant level starting at the full mark).

Because of the differences in the approach and test methods of the various engine manufacturers, it is important that these tests be performed strictly in accordance with the engine manufacturer’s requirements. Be sure that the engine water pump is producing pressure within 15 seconds regardless of what test is being performed.

A brief description of some of the deaeration tests required by various manufacturers is given below for general information only. Refer to the engine manufacturer’s requirements for details.

Deaeration tests are to be performed after determination of the expansion volume.

After determination of the expansion volume, replace the operating thermostat(s), with blocked-open thermostat(s) (except where noted) and refill the system with a hose until the filler-neck overflows. Run the engine at approximately rated speed for 5 minutes and refill the system to the bottom of the filler-neck extension or other “Full” mark. One or more of the following deaeration tests may then be required:

3.1.4.1 Test 1 (Deaeration of Fill-Entrained Air)

Run the engine at an approximately rated speed with blocked open thermostat(s), without a pressure cap, and with the shutters closed or the airflow to the radiator blocked with cardboard segments to maintain a top-tank temperature of 65 °C ± 6 °C (149 °F ± 11 °F). Run until a sight glass in the engine outlet (radiator inlet) runs clear of air bubbles. The time from refilling to the bottom of the filler-neck extension until the sight glass runs clear of bubbles shall not exceed the manufacturer’s specification, e.g., 25 minutes.

3.1.4.2 Test 2 (Continuous Deaeration)

Using a special vented pressure cap with the vent hose led to an inverted coolant-filled bottle set in a bucket of coolant for purposes of measuring the volume of vented air, run the engine at approximately rated speed with blocked-open thermostats and with the shutters closed or the airflow to the radiator blocked with cardboard segments to maintain a top-tank temperature of 65 °C ± 6 °C (149 °F ± 11 °F).

Inject air into the system via the heater return circuit or equivalent closed loop branch, from a pressurized air source adjusted to produce visible bubbles in a sight glass. Measure the time required to fill the inverted bottle with air vented from the system while monitoring the pump pressure rise. The pump pressure rise is plotted against air venting rate (volume of bottle/time to fill with air). Gradually increase the pressure of air injected into the system, allowing the filled system to stabilize for at least 3 minutes before each data point. Take several data points at increasing air injection pressures. The rate of air venting that gives a 35% loss in pump pressure rise must equal or exceed an amount specified by the engine manufacturer, e.g., 5% of engine displacement per minute.

3.1.4.3 Test 3 (Continuous Deaeration)

With the pressure cap on, run the engine at an approximately rated speed with blocked open thermostats and with the shutters closed or the airflow to the radiator blocked with cardboard segments to maintain a top-tank temperature of 65 °C ± 6 °C (149 °F ± 11 °F).

Inject air via the heater return circuit or equivalent closed loop branch at a rate specified for each engine model (e.g., 2.8 L/min [0.1 cfm] per cylinder) and monitor the water pump flow. At the specified air injection rate, the coolant pump flow (not pressure) must not degrade more than the manufacturer's required value, e.g., 50%, and the coolant loss must not be more than the drawdown rating (determined in 3.1.5).

3.1.4.4 Test 4 (Deaeration with Operating Thermostat(s))

Run the engine at high idle for 5 minutes with operating thermostat(s) and without pressure cap. Bring engine to low idle and fill system to appropriate full level. Install the pressure cap. With the shutters closed or the airflow to the radiator blocked with cardboard segments, run at high idle for 10 minutes more, keeping engine coolant outlet temperature between approximately 82 °C (180 °F) and 93 °C (200 °F). Run at 50 to 150 rpm higher than torque peak engine speed up to 20 minutes more, keeping engine coolant outlet temperature between approximately 82 °C (180 °F) and 93 °C (200 °F). The system has acceptable deaeration capability if a sight glass runs clear of bubbles in the manufacturer's specified time period.

3.1.5 Drawdown

This test determines the reserve quantity of the cooling system and the correct position of the low mark in the radiator top tank or expansion tank. Note that in all test cases, the drawdown volume must exceed that volume refilled during cold fill. If equipped, it is also convenient to evaluate the low coolant sensor operation and check engine light during the drawdown test.

3.1.5.1 Test 1 (Drawdown by Loss of Pump Pressure)

Run engine at rated engine speed with blocked open thermostats, without a pressure cap and with shutters closed or the radiator blocked with cardboard to maintain a top tank temperature of approximately 82 °C (180 °F). Add or remove coolant until the system is filled to the bottom of the filler neck extension or to the specified "Full" level. Install the pressure cap. Record the water pump pressure rise to establish a reference pump rise, then drain off coolant in increments of 1 L (1 quart) at a point of positive pressure and record pump pressure rise after each unit of coolant is removed. Remove coolant slowly until there has been a 15% loss in pump pressure rise from the reference pump rise. The water pump rise loss at the low coolant level mark must not be more than 10% from the reference pump pressure rise. The volume of coolant drawn from the system, expressed as a percent of the total system volume, is the drawdown volume. This volume is specified by the manufacturer, e.g., minimum of 12% of the total system volume including the expansion volume as described in 3.1.3 plus another 6% or more of the system volume between the full mark and low mark. This requirement may vary, or sometimes not apply to HD off highway construction and industrial equipment. It is suggested to review the design with the engine manufacturer.

3.1.5.2 Test 2 (Drawdown by Aeration)

After the deaeration tests, run the engine at governed no-load speed, with blocked-open thermostat(s), without a pressure cap, and with the shutters closed or the radiator blocked with cardboard segments to maintain top-tank temperature at 65 °C ± 6 °C (149 °F ± 11 °F). When the temperature is reached, add or draw off coolant until the system is filled to the bottom of the filler-neck extension or other “Full” mark. Install the pressure cap. Then draw off coolant slowly in 1 L (1 quart) increments from system at a point of positive pressure and measure until a continuous stream of air is seen in engine-outlet sight glass. The amount of coolant drawn off, expressed as a percent of total-system capacity, is the drawdown rating. This volume is specified by the manufacturer, e.g., equal to or greater than 11% of the total-system capacity, but not less than a specified minimum, for systems up to 95 L (100 quart) capacity. For most manufacturers, this specified minimum drawdown rating is 3 L (3 quarts). However, some engine manufacturers require higher minimums. For cooling systems with capacity above 95 L (100 quarts), the drawdown rating is typically 10.5 L (11 quarts) plus 4% of the system capacity in excess of 95 L (100 quarts). If a remote surge tank is used and it is not located above or higher than all other system components, there may be additional drawdown test requirements. Review the design with the engine manufacturer.

3.1.6 Total System Capacity

Following the drawdown test, drain and measure the coolant from the entire system, being careful that no fluid is trapped in the system. This volume of fluid drained, added to the amount drawn off during the drawdown test, is the total-system capacity. System capacity may also be determined during initial fill of a known dry system, or from virtual modeling.

3.1.7 Other Requirements

Individual engine manufacturers may have additional cooling system tests or system parameters that they require. Refer to the engine manufacturer’s requirements. A sampling of some of these requirements follows:

3.1.7.1 Pump Cavitation

Prior to the start of testing, be sure a blocked open thermostat is installed, and the system is completely filled with coolant. In addition, some means will be needed to warm up the coolant such as disconnecting the fan belts, temporarily disabling the fan drive, blocking fan airflow, etc. The pressure cap should be removed throughout the test. Starting with water pump inlet temperature below 49 °C (120 °F), record water pump inlet temperature and pump pressure rise as the coolant temperature rises while the engine speed is held constant at the rated speed. Record the pump rise at 49 °C (120 °F) as a reference pump rise. Care should be taken to measure pump pressure rise with a differential pressure gage, not subtract the value of two gage pressures where the measurement error of the two is additive. Control the coolant warm-up rate to approximately 2 °C (4 °F) rise every 2 minutes to assure accurate data and record the pump inlet temperature and pump pressure rise at least every 5 °C (9 °F) below 85 °C (185 °F) and every 2 °C (4 °F) above 85 °C (185 °F) water pump inlet temperature. Adjust the pump pressure rise to the density of the coolant at 49 °C (120 °F), and observe the pump rise loss at each point. Continue running until either the system has exceeded the pump rise loss limit set by the manufacturer (e.g., 10% or 20% rise loss) or has exceeded the minimum required cavitation temperature as specified by the manufacturer. Since altitude can have an effect on the boiling point of coolant, the final cavitation temperature should be adjusted to 100 kPa (29.6 in Hg) barometer pressure by adjusting the observed cavitation temperature by 0.33 °C for each kPa (1 °F for each 0.5 in Hg) the test site barometric pressure differs from 100 kPa (29.6 in Hg).

3.1.7.1.1 Water Pump Inlet Pressure Conditions

With the pressure cap installed, it is desirable that the water pump inlet pressure does not fall below atmospheric pressure. One of the following alternatives will probably be specified by the engine manufacturer:

3.1.7.1.1.1 Water Pump Suction

Suction at the inlet to the water pump shall not exceed 10.2 kPa (3 in Hg) at engine high idle, without a pressure cap, and with the thermostats open.

3.1.7.1.1.2 Water Pump Inlet Pressure

With the pressure cap installed from an initial cold start, there shall be a positive pressure above atmosphere at the inlet to the water pump at all times throughout the entire warm up phase. After the system has reached a temperature of approximately 88 °C (190 °F) at the engine outlet (or thermostat start to open plus 3 °C [5 °F]), sweep engine speed from high idle to rated speed. Through this phase, the pump inlet pressure is allowed to drop to atmospheric pressure but is not allowed to drop past the pump NPSHr (Net Positive Suction Head rating) as defined by the manufacturer. This pump inlet pressure requirement is usually not applicable to a hot restart condition.

3.1.8 The following are special considerations for systems with surge tanks or coolant recovery systems:

3.1.8.1 An engine cooling system which has a surge tank can be considered to have a remote-mounted radiator top tank. For purposes of these tests, the surge tank shall be considered to be the radiator top tank. Filling should be accomplished through the filler neck on the surge tank. The surge tank will be provided with a filler-neck extension or the other cold-fill "Full" mark. The expansion volume for the system is provided in the surge tank in the same manner as in the usual radiator top tank. The total-system capacity includes the volume of the surge tank to the bottom of the filler-neck extension or the other cold-fill "Full" mark.

3.1.8.2 An engine cooling system which has a coolant recovery system can be considered to have a remote-mounted expansion volume only. For purposes of this test, filling should be accomplished through the radiator filler neck, to the bottom of the filler neck, through the coolant recovery system tank inlet, and to the recommended cold-fill level. The expansion volume for the system is provided in the coolant recovery system tank and is equal to the volume from the recommended cold-fill level to the top of the tank.

3.2 Automotive Applications

3.2.1 Definitions

3.2.1.1 MAXIMUM COLD FILL MARK

Coincides with the maximum amount of coolant the total system is filled to during service fill procedure. This mark is important to be included in coolant reservoir tanks as some of the lines included in Figures 1 and 2, are referenced to this line.

3.2.1.2 MINIMUM COLD FILL MARK

Coincides with the minimum cold fill required for the system to function properly. This mark is important to be included in coolant reservoir tanks as some of the lines included in Figures 1 and 2, are referenced to this line.

3.2.1.3 MAXIMUM HOT FULL LEVEL

This is determined by adding 6 to 7% of the system coolant volume to the maximum cold fill volume.

3.2.1.4 DRAWDOWN (LOWEST COOLANT LEVEL)

The quantity of coolant that can be lost before impairing cooling system performance, or degrading the cooling level, under normal operating conditions.

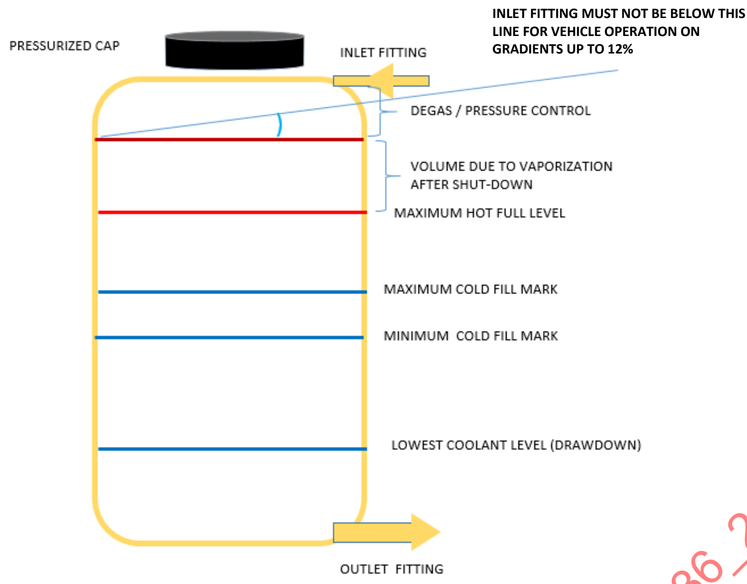

Figure 1 - Coolant surge tank (pressurized) levels identification

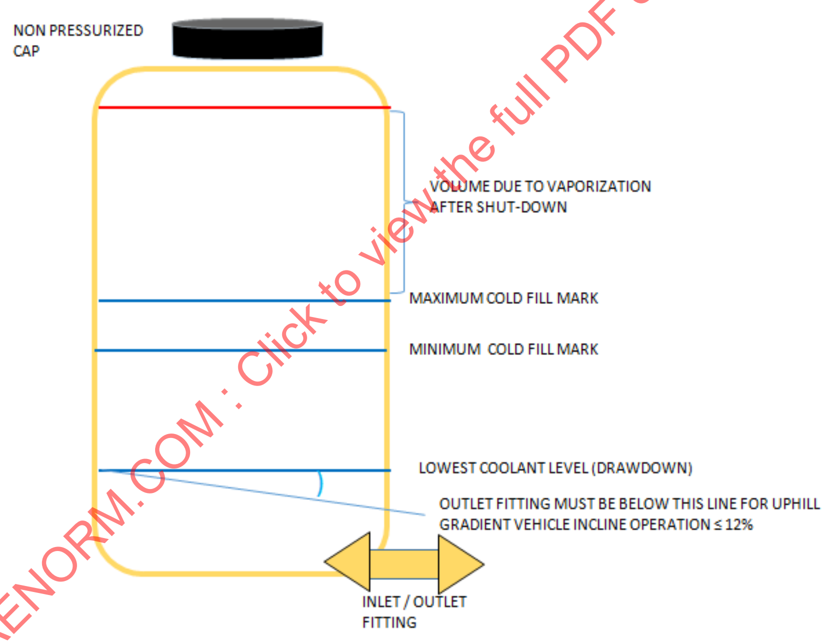

Figure2 - Coolant reservoir tank (unpressurized) levels identification

3.2.1.5 DEAERATING LEVEL

This is determined by adding 2% system coolant volume to the hot full volume.

3.2.1.6 COOLANT

A liquid used to transport heat from one point to another; typically, a mixture of 50% water and 50% engine coolant concentrate by volume.

3.2.1.7 DEGAS SYSTEM

A subsystem that consists of a deaerating tank, pressure cap, and the hoses that connect the tank to the cooling system. The degas system provides a volume for expansion of the coolant as it is heated, providing system pressure regulation, a system fill location, as well as a means of deaerating the coolant. Degas systems can be routed to either actively function in all thermostat operating position, or active only in the open thermostat position and passively in the closed thermostat operating position.

3.2.1.8 COOLANT RECOVERY SYSTEM

A subsystem for the purpose of containing the coolant in the system when it expands due to an increase in temperature. Sometimes called an overflow system, the recovery system consists of a tank that is partially filled and attached to the vent on a filler neck of a full and pressurized radiator. As the coolant heats and expands it forces fluid into the auxiliary tank, and when the coolant cools a vacuum is created that draws fluid from the tank back into the radiator. A pressure-vacuum cap is required for this type of system.

3.2.2 Vehicle Preparation

3.2.2.1 Facilities

Test facilities must be equipped to adequately vent coolant vapors and exhaust gasses. Do not conduct tests in the presence of spark or flame or any source of ignition.

3.2.2.2 Leveling

Before starting any test, the vehicle shall be in a plane parallel to the horizontal level.

3.2.2.3 Soaking

Allow the engine of the vehicle and coolant to reach ambient temperature (overnight).

3.2.2.4 Drain

3.2.2.4.1 Remove the system fill cap. Add or remove coolant to bring the system to the specified maximum coolant fill line.

3.2.2.4.2 Drain the coolant from the system by opening the radiator drain valve and any drain valves on the engine, recording time for coolant to drain.

3.2.2.4.3 Remove the lower radiator hose from the radiator and drain coolant. Remove any remaining hoses or components which may be required to completely drain the system. Heater core circuits and inlet controlled cooling systems are especially sensitive to coolant removal.

3.2.2.5 Measure and record the total amount of coolant drained in 3.2.2.4.2 and 3.2.2.4.3 (volume A). Reinstall/reseal any removed or opened components and reconnect all removed or opened hose connections and close the radiator and engine drain valves.

3.2.3 Filling

3.2.3.1 Starting with a volume of coolant drained in 3.2.2.4, fill the system with coolant through the designed fill location (opening any required bleed locations). Pour coolant into the fill location as fast as the system will allow and record the time to reach a filled condition (with a degas system, this will be the time to fill the system to the maximum fill mark in the reservoir; with a coolant recovery system, this will be the time to completely fill the radiator and then the recovery reservoir to the maximum fill mark). Record whether the fill process must be stopped at any time to allow air to escape. After the system has been filled, record the remaining volume of coolant (volume B). With the engine off, thermostat closed, a drained system shall fill with coolant at a rate that is compatible with customer and technician expectations, based on other vehicles in the same class. If the time to fill is excessively long, then service costs will be high, and more importantly, if there are excessive bleed ports or components which must be removed for proper filling, the chance of a technician miss-filling or not being able to add the critical minimum amount of coolant may result in the cylinder head bottom surface of the coolant jacket to become uncovered (the critical volume that would cause the cylinder head bottom surface of the coolant jacket to become uncovered can often be determined from a CAD check).

3.2.3.2 Start the engine, and while it idles, monitor the coolant level and temperature. Top off the coolant as air is purged to the top tank or degas bottle. As soon as the thermostat opens, or the coolant begins to expand into the reservoir, install the radiator or degas pressure cap and close any bleed locations. The opening of the thermostat may be detected by observing the flow in a radiator inlet line sight glass (if used, the sight glass should not affect system volume), or by noting a sudden rise in inlet line or top-tank temperature, or by noting when the coolant temperature exceeds the thermostat rating by 3 °C (5 °F) for outlet-controlled systems or 6 °C (11 °F) for inlet controlled systems. Watch for any indications of overheating. Increase engine speed to 2500 to 3000 rpm, or as specified by the manufacturer. Continue running the engine until a sight glass in the radiator outlet hose runs clear of bubbles. Due to the complexity of some systems, the manufacturer may have a specific engine speed/time schedule to follow to ensure proper purging of air. If this is the case, one should always default to the manufacturers recommended fill schedule to ensure inadvertent damage to the vehicle’s powertrain does not occur. If the coolant level falls below the minimum fill mark, stop the engine, remove the fill cap and fill to the maximum fill mark from the remaining coolant volume “B” as determined in 3.2.3.1, then reinstall the pressure cap. Some vehicles have thermostat opening temperatures that are above the boiling temperature of coolant at atmospheric pressure, so take appropriate care when removing the fill cap due to the possibility of high pressures in the cooling system (the system may vent vapor, or spit out coolant, and the pressure in the system may exert an unexpected amount of force on the cap when the cap is loose from the filler neck). Measure and record the time it takes from the time the thermostat opens to the time that the sight glass is clear of bubbles. This recorded time shall be compatible with customer and technician expectations, as a guideline this time should be less than 25 minutes. Stop the engine and let the engine and coolant reach ambient temperature (takes a couple hours, best if left overnight), and measure the amount of coolant required to refill the system to the maximum fill mark (volume C).

3.2.3.3 The difference in volume of coolant added (volume B-volume C) is the volume of the air remaining in the system after the initial fill. This volume shall be less than the volume of the reservoir between the minimum and maximum fill marks (because this is equal to the amount of air remaining in the system, and there shall be enough coolant in the reservoir to make up the volume of air in the system when the air is eventually purged).

3.2.4 Expansion Volume

3.2.4.1 The cooling system shall provide an adequate volume to accommodate expansion of the coolant. The expansion volume required is a combination of static expansion volume due to the change in system temperature, and the dynamic or surge volume required to prevent coolant loss as a result of after-boil following engine shut-down.

3.2.4.2 Historically, the minimum coolant expansion volume required has been specified at 6 to 8% of the total coolant volume. This is based on the change in specific volume of a 50% glycol coolant between the temperatures of 20 °C (68 °F) and 124 °C (255 °F) (which is equal to 7%). This should be verified through testing since the volume required may vary with system compliance due to hose material selection (which may affect hose expansion), system degas selection, and engine design (which may affect the amount of vapor formed during engine shut-down).