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SURFACE VEHICLE INFORMATION REPORT

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(R) Requirements for Engine Cooling System Filling, Deaeration, and Drawdown Tests

1. *Scope*

This SAE Information Report is applicable to all engine cooling systems used in heavy-duty vehicles, industrial applications, and automotive applications

1.1 Purpose

The purpose of this document is to list the requirements which are in general use for filling, deaeration, 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 report. 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 for information purposes only, and does not constitute a SAE Standard.

2. *References*

There are no referenced publications specified herein.

3. *Leveling*

Before starting any test, the vehicle or the industrial equipment must be level.

<u>Heavy Duty and Industrial Applications</u>

4. *Filling*

With the engine off, thermostats closed, a completely drained system (including heater, other accessories, and their lines) must fill with cold water at the manufacturers recommended fill rate (for example: 19 L/min ± 2 L/min (5 gpm ± 0.5 gpm) or 11.3 gpm + 1 L/min (3 gpm + 0.3 gpm)) with hose until the filler neck overflows. Engine manufacturer's instructions on venting the engine and accessories must be followed to achieve the specified fill rate.

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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 min, and then stop the engine and measure the amount of water 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 water added shall not exceed 10% of the total system capacity, defined in this document. 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 water added exceed the system drawdown rating, defined in this document.

The test applies in general to systems of up to 95 L (100 qt) capacity. However, lower fill rates [for example, 11 L/min (3 gpm)] may be required in special instances and will be specified by the engine manufacturer. For systems over 95 L (100 qt) 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.

5. Expansion Volume

The radiator must provide an expansion volume equal to a minimum of 6% of the total-system capacity. This expansion volume will remain empty during a cold-fast fill, but provision shall be made to vent the air from this space to the filler-neck during normal gradual engine warm up. The amount of water required to slow fill the radiator from the bottom of the filler-neck extension to the breather hole [usually 3.2 mm (0.12 in) diameter] in the filler-neck extension, expressed as a percent of the total-system capacity, is the percent expansion volume.

Provision for a filler-neck extension tube is the preferred construction for radiators for heavy-duty and industrial applications. However, if a filler-neck extension is not provided, the amount of water required to fill the radiator from the recommended "Full" mark to the bottom of the filler neck, expressed as a percent of the total-system capacity, is the percent expansion volume. Total-system capacity is defined following the requirements for drawdown testing.

6. Deaeration Tests

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 vortexing at the fill line (shunt line) connection when a vehicle is not operating on a level surface or due to centrifugal forces in a prolonged turn, or from combustion gases leaking across cylinder-head seals.

Because of the differences in the approach and the test methods of the various engine manufacturers, it is important that these tests be performed strictly in accordance with the engine manufacturer's requirements.

A brief description of some of the deaeration tests required by various manufacturers is given in the document 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 min 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:

6.1 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 sightglass 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 25 min.

6.2 Test 2 (Continuous Deaeration)

Using a special vented pressure cap with the vent hose led to an inverted water-filled bottle set in a bucket of water 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 and measure the volume of air vented by the deaeration system while monitoring the pump-pressure rise. The rate of air venting when a 35% loss in pump-pressure rise occurs must equal or exceed an amount specified for each engine model.

6.3 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 at a rate specified for each engine model [approximately 2.8 L/min (0.1 cfm) per cylinder] and monitor the water pump flow. At the specified air-injection rate, the water pump flow must not fall below 50% of the original value, and the coolant loss through the overflow line must not be more than the drawdown rating (determined in Section 7).

6.4 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. 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 in the engine outlet (radiator inlet) runs clear of air bubbles in the allotted time period.

7. Drawdown

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.

7.1 Test 1

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). Start with the radiator brim full and record the water pump pressure rise to establish a reference pump rise, then drain off water in increments of 1 L (1 qt) at a point of positive pressure and record pump pressure rise after each unit of water is removed. Remove water 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 water drawn from the system, expressed as a percent of the total system volume, is the drawdown volume. This volume must be equal or greater than 12% of the total system volume and is expected to include the expansion volume as described in Section 5 plus another 6% or more of the system volume between the full mark and low mark.

7.2 Test 2

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 water until the system is filled to the bottom of the filler-neck extension or the other "Full" mark. Then draw off water slowly in 1 L (1 qt) increments from system at a point of positive pressure and measure until air is seen in engine-outlet sight glass. The amount of water drawn off, expressed as a percent of total-system capacity, is the drawdown rating. This must be 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 qt) capacity. For most manufacturers, this specified minimum drawdown rating is 3 L (3 qt). However, some engine manufacturers require higher minimums. For cooling systems with capacity above 95 L (100 qt), the required drawdown rating shall be 10.5 L (11 qt) plus 4% of the system capacity in excess of 95 L (100 qt). 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.

8. Total System Capacity

Following the drawdown test, drain and measure the water 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.

9. 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:

9.1 Pump Cavitation

Prior to the start of testing, be sure a blocked open thermostat is installed and the system is completely filled with water. In addition, some means will be needed to warm up the coolant such as disconnecting the fan belts, blocking fan airflow, etc. The pressure cap should be removed through the test. Starting with water pump inlet temperature below 49 °C (120 °F), record water pump inlet temperature and pump pressure rise as the water temperature rises while the engine speed is held constant at the rated speed. Record the pump rise at 49 °C (120 °C) as a reference pump rise. Control the coolant warm-up rate to approximately 2 °C (4 °F) rise every 2 min 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 water 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 (usually either 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 water, 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).

9.2 Water Pump Inlet Pressure Conditions

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:

9.2.1 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.

9.2.2 Water Pump Inlet Pressure

There shall be a positive pressure above atmosphere at the inlet to the water pump at all times.

10. Special Considerations for Systems with Surge Tanks or Coolant Recovery Systems

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.

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, filling to the bottom of the filler neck, and through the coolant recovery system tank inlet, filling 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.

<u>**Automotive Applications**</u>

11. Definitions

11.1 Maximum fill mark

Coincides with the fluid level obtained at maximum fluid system temperatures.

11.2 Minimum fill mark

Coincides with the minimum fill required in a cold system for the system to function properly.

11.3 Drawdown

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

11.4 Coolant

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

11.5 Degas System

A subsystem that consists of a de-aerating tank 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, as well as a means of de-aerating the coolant.

11.6 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.

12. Vehicle preparation

12.1 Leveling

Before starting any test, the vehicle shall be level.

12.2 Soaking

Allow the vehicle, engine, and coolant to reach ambient temperature (overnight) and top off coolant to the 100% cold fill level.

13. 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.

14. Drain

14.1 Remove the system fill cap.

14.2 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.

14.3 Remove the lower radiator hose from the radiator and drain coolant.

14.4 Measure and record the total amount of coolant drained in paragraphs 14.2 and 14.3 (volume A). Reinstall the lower radiator hose and close the radiator and engine drain valves.

15. Filling

15.1 Starting with a volume of coolant drained in paragraph 14, 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, would cause 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).

15.2 Install the radiator cap and close any bleed locations. Run the engine at approximately rated speed until the thermostat opens. The opening of the thermostat may be detected by observing the flow in a radiator inlet line sight glass, 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. Watch for any indications of overheating. Continue running the engine until a sight glass in the radiator outlet hose runs clear of bubbles. If the coolant level falls below the minimum fill mark, stop the engine, remove the fill cap and fill to the maximum fill mark. 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 min. 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).

15.3 The remaining volume of coolant (Volume B-Volume C) shall be less 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 makeup the volume of air in the system, when the air is eventually purged).

16. Expansion Volume

16.1 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.

16.2 Historically, the minimum coolant expansion volume required has been specified at 6 or 7% 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 and 124 °C (which is equal to 7%). This should be verified through testing since the volume required may vary with hose material selection (which may affect hose expansion) and engine design (which may affect the amount of vapor formed during engine shut-down).

16.3 To measure the expansion due to temperature change of the coolant, mark the level of the coolant in the reservoir or header tank when the vehicle is completely cold (vehicle has not been started for 8 hours), level 1, see Figure 1. Provide a means of capturing any coolant that is vented during the test. Then start the vehicle and increase the coolant temperature by means of increasing load and ambient temperature (as in a wind tunnel test), or by means of blocking the airflow through the grill. Allow the coolant temperature to reach the maximum allowable as determined by the engine manufacturer. Mark the level of the coolant under these conditions on the reservoir or header tank (level 2). Then shut down the vehicle and mark the maximum coolant level achieved in the first 5 min after shutdown (level 3). Since the system may vent steam or coolant during this test, it is advisable to wear safety goggles, and other protective gear to prevent burns from escaping steam and remember that steam could suddenly vent from the system at any time. After the vehicle is completely cooled, the header tank or reservoir can be removed, to measure the volume between the marks. Include any coolant volume that was vented out of the system during testing.

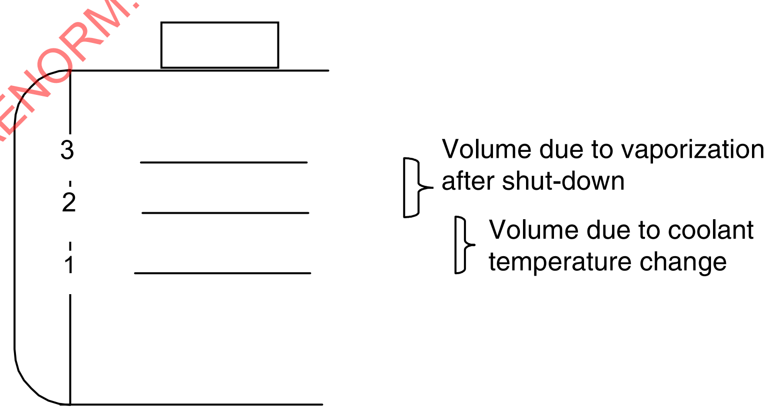

FIGURE 1—COOLANT RESERVOIR MARKING