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SURFACE VEHICLE RECOMMENDED PRACTICE

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On-Highway Truck Cooling Test Code

Foreword—This reaffirmed document has been changed only to reflect the new SAE Technical Standards Board format. Definitions have been changed to Section 3. All other section numbers have changed accordingly.

1. Scope—The purpose of this SAE Recommended Practice is to establish a testing procedure to determine the performance capability of the engine cooling system and, if so equipped, the charge air cooling system on on-highway trucks with liquid-cooled internal combustion engines.

1.1 Objective—Testing is generally conducted to determine compliance with criteria established by the engine manufacturer or the end product user to meet a desired engine reliability goal. Usually the criteria are based on maximum engine coolant temperature, maximum intake manifold temperature, ambient air temperature, altitude, vehicle speed or ram air speed, engine load, and engine speed.

This test code procedure is primarily for use with a wind tunnel and a chassis or drivetrain dynamometer facility. While this procedure applies to on-highway trucks, it also applies to the on-highway operating mode of specialized vehicles such as fire trucks, cranes, drill rigs, etc., that have dual-purpose engines. Vehicles equipped with side- or rear-mounted radiators may require an alternate procedure of a towing dynamometer because of peculiar aerodynamics.

2. References—There are no referenced publications specified herein.

3. Definitions

3.1 EOTD—Engine Outlet Temperature Differential—The difference between the coolant temperature at the engine outlet and the ambient temperature measured in front of the grille.

3.2 Terms Used by the Industry Related to EOTD

3.2.1 ATB—AIR-TO-BOIL—The ambient temperature at which the engine coolant outlet would reach 100 °C (212 °F), the boiling point of water at standard conditions. This is a common term in the industry, but can sometimes be confusing to the beginner as it does not allow for pressurized systems, the effect of barometric pressure or the effects of glycol and coolant conditioner type solutions.

3.2.2 AMBIENT CAPABILITY—Similar to ATB, but some temperature other than the boiling point of water is used as the reference engine outlet temperature, usually 99 °C (210 °F).

3.2.3 TTTD—TOP TANK TEMPERATURE DIFFERENTIAL (ALSO KNOWN AS TTD—TOP TANK DIFFERENTIAL)—The difference between the coolant temperature at the radiator top tank and ambient. The terminology does not allow for cross flow radiators or auxiliary heat exchanger between the engine outlet and the radiator inlet.

3.2.4 ATW—AIR TO WATER—Temperature differential between ambient and engine outlet temperature. The terminology assumes water as the coolant.

3.2.5 IMTD—INTAKE MANIFOLD TEMPERATURE DIFFERENTIAL—The difference between the temperature of the combustion air in the intake manifold and the ambient temperature measured in front of the grille.

3.2.6 INSTALLED CHARGE AIR COOLING SYSTEM EFFECTIVENESS—The effectiveness of the CAC system using the temperatures at the turbocharger outlet and intake manifold inlet rather than the temperatures at the CAC inlet and CAC outlet (See Equation 1.)

$$\text{CAC System Effectiveness} = \frac{\text{Turbocharger Outlet Temperature} - \text{Intake Manifold Temperature}}{\text{Turbocharger Outlet Temperature} - \text{Ambient Temperature}} \quad \text{(Eq. 1)}$$

3.2.7 RTD—RESISTANCE TEMPERATURE DETECTOR—Measures temperature by a change in resistance with a change in temperature.

4. Facility Requirements—The test facility should provide the following features.

4.1 Power Absorbing Device—A chassis or drivetrain dynamometer capable of absorbing rated horsepower and peak torque of the engine/vehicle.

4.2 Cooling Air—Constant air velocity and air temperature to the face of the radiator within the range recommended by the engine manufacturer.

4.3 Instrumentation to measure the required elements and test conditions.

5. Test Preparation and Set Up

5.1 Engine and Vehicle

5.1.1 The engine coolant thermostat(s) should be blocked to the manufacturer's specified opening for maximum design operating temperature condition.

5.1.2 The fan drive, if unit is so equipped, should be fully engaged using the manufacturer's recommended procedure.

5.1.3 All shutters should be fixed in the fully open position.

5.1.4 Air conditioning should be on "normal", coldest temperature setting; and fan speed on "high." Cab windows and vents are to be open to assure that the A/C compressor does not cycle during stabilization.

5.1.5 Cab heater fan should be "off" if different from air conditioning fan.

5.1.6 Block the coolant flow through the cab heater hoses at engine.

5.1.7 Determine that the oil levels are proper.

5.1.8 The air compressor on vehicles so equipped should be held in the disengaged mode. This can readily be accomplished by applying sufficient shop air to the air compressor discharge or wet tank to prevent the governor from turning on the compressor. This is very important when the air compressor inlet is taking clean air from the intake manifold.

5.2 Insure engine coolant is replaced with water or at a 50/50 glycol solution concentration or as required by the engine manufacturer's test procedure.

5.3 Instrumentation and Data Log

5.3.1 PRIMARY

5.3.1.1 Time Interval

5.3.1.2 Engine Speed

5.3.1.3 Fan Speed

5.3.1.4 Fuel Flow Rate Measurement and Temperature—Follow the engine manufacturer's recommended procedure if one exists. The temperature of the fuel delivered to the engine should normally be maintained at or near 38 °C (100 °F).

5.3.1.5 Ambient Air Temperature and Relative Humidity

5.3.1.6 Velocity and temperature of ram air measured 1.0 m (3.3 ft) in front of the grille and on the approximate centerline of the grille opening (may or may not coincide with the centerline of the fan and/or the engine).

5.3.1.7 Coolant Temperature at the Engine Outlet to the Radiator—If a sensitive RTD type device is used, it is advisable to measure this temperature in the radiator hose to reduce the effect of engine vibration. This temperature should be measured as close to the engine coolant outlet as reasonably possible.

5.3.1.8 Dimensional Relationship of Fan to Core, Shroud, and Engine

5.3.1.8.1 Fan to shroud tip clearance at top, at bottom, and at both sides. This is to determine the centering of the fan in the shroud.

5.3.1.8.2 Back of fan to back of shroud at top, at bottom, and at both sides. This is required for fan penetration into the shroud.

5.3.1.8.3 Back of fan to back of radiator at top, at bottom, and at both sides. This is to determine the proximity of the fan to the core.

5.3.1.8.4 Back of fan to closest point on engine or engine affixed hardware. This will help the decision-making process when it becomes desirable to change the fan penetration into the shroud.

5.3.1.9 Test Site Altitude and Observed Barometric Pressure

5.3.2 SECONDARY

5.3.2.1 Road Speed

5.3.2.2 Transmission Gear

5.3.2.3 Dynamometer Power

5.3.2.4 Rear Axle Lubricant Temperature

5.3.2.5 Oil Temperature and Pressure of

5.3.2.5.1 Engine for monitoring and abort purposes

5.3.2.5.2 Transmission (if equipped with a transmission cooler)

5.3.2.6 Water Pump Inlet and Outlet Pressures

5.3.2.7 Coolant Temperature at Engine Inlet from the Radiator

5.3.2.8 Coolant Flow Rate at Engine Outlet to Radiator

5.3.2.9 Combustion Air Temperature at

5.3.2.9.1 Entrance to air induction system

5.3.2.9.2 In air cleaner before element

5.3.2.9.3 Turbo inlet for turbocharged engines

5.3.2.9.4 Intake manifold inlet or in the manifold

5.3.2.9.5 Exhaust gas at the turbo outlet

5.3.2.10 Combustion Air Pressures

5.3.2.10.1 Air cleaner exit measured at location provided for air cleaner restriction gage.

5.3.2.10.2 Turbo Outlet Pressure (Turbocharged Engines Only)—A port location in the turbo outlet should be specified by the engine manufacturer if accurate data is critical. Otherwise it may be permissible to weld a fitting on the pipe leading from the turbo outlet. If this is done, the most accurate data will be obtained if a piezometer ring is added to the pipe within 60 mm (2.5 in) of the turbo end of the pipe.

CAUTION—Pressure transducers should not be located where the elevated engine compartment temperatures will cause them to be inaccurate.

5.3.2.10.3 Intake Manifold Pressure (Turbocharged Engines Only)—A port location in the intake manifold should be specified by the engine manufacturer if accurate data is critical. Otherwise it may be permissible to weld a fitting on the pipe leading to the intake manifold. If this is done, the most accurate data will be obtained if a piezometer ring is added to the pipe within 60 mm (2.5 in) of the intake manifold end of the pipe.

CAUTION—Pressure transducers should not be located where the elevated engine compartment temperatures will cause them to be inaccurate.

5.3.2.11 Cooling Air Temperature at Exit Face of Radiator Core—Preferably measured in five locations. The primary temperature should be measured at the center of the core. The other four temperatures should be measured at locations one fifth of the core width inward from the right and left core edge and one fifth of the core height inward from the top and bottom edges. Similar temperatures should be measured at the cooling air entrance face of the radiator core if accurate radiator performance calculations are to be performed.

5.3.2.12 On air-to-air charge air coolers (if so equipped), the cooling air temperature behind the CAC core measured in five locations, one temperature should be measured at the center of the core. Four temperatures should be measured at locations one fifth of the core width inward from the right and left core edge and one fifth of the core height inward from the top and bottom edges. Similar temperatures should be measured at the front face of the CAC core if accurate CAC performance calculations are to be performed.

5.3.2.13 On air-to-coolant charge air coolers (if so equipped), it is advisable to measure the temperature of the coolant entering and exiting the heat exchanger if possible.

6. Procedure

6.1 Adjust the ram air velocity to maintain the test speed specified by the engine manufacturer, for example, 24 km/h (15 mph).

6.2 Start engine and run at rated power and speed until stabilization occurs. Stabilized conditions exist when (a) engine speed and load have remained constant (within reason) for at least 15 min and (b) the EOTD does not change more than ±0.3 °C (0.5 °F) between three consecutive sets of readings taken at 5 min intervals. The temperature of the engine lubricant in the sump should also be stabilized to within ±0.3 °C (0.5 °F) between three consecutive sets of readings taken at 5 min intervals.

6.3 Record data documenting stabilization.

6.4 Adjust load to run engine at peak torque and speed or other specified cooling check point until stabilization occurs.

6.5 Record data documenting stabilization.

7. Test Data Evaluation

7.1 **Engine Outlet Temperature Differential (EOTD)—**Test data is used to determine the cooling system performance capability referred to as EOTD. It is defined as the difference between the coolant temperature at the engine outlet (Tc) and the temperature of the ambient air (Ta). The EOTD is the quantity to which corrections (discussed later) can be applied for inaccuracies in fueling rate (see Equation 2).

$$\begin{aligned} EOTD(°C) &= Tc(°C) - Ta(°C) \\ EOTD(°F) &= Tc(°F) - Ta(°F) \end{aligned} \qquad \text{(Eq. 2)}$$

7.2 **Air-to-Boil Temperature (ATB)—**The EOTD is used to determine the cooling system performance capability commonly referred to as air-to-boil temperature (ATB). Air-to-boil is defined as the ambient air temperature (Ta) at which the coolant temperature at the engine outlet (Tc) reaches the boiling temperature of water at standard conditions, 100 °C (212 °F) (see Equation 3).

$$\begin{aligned} ATB(°C) &= (100 - Tc) + Ta = 100 - EOTD(°C) \\ ATB(°F) &= (212 - Tc) + Ta = 212 - EOTD(°F) \end{aligned} \qquad \text{(Eq. 3)}$$

Air-to-boil capabilities are calculated for each combination of ram air velocity, engine load, and engine speed specified by the engine manufacturer or the end user.

8. Test Results Extrapolation and Adjustment Guidelines

8.1 Due to facility limitations or existing ambient air conditions, actual test conditions may deviate from those specified by the acceptance criteria. EOTD temperatures based on test results may be adjusted for variations.

8.1.1 ALTITUDE—When the test is conducted at an altitude above the base of 152 m (500 ft), the calculated EOTD should be adjusted downward 1 to 2 °C (2 to 4 °F) per 305 m (1000 ft) of elevation.

8.1.2 COOLANT—When a test is conducted with water instead of an engine manufacturer specified 50/50 ethylene glycol-water mixture coolant base, the calculated EOTD temperature should be adjusted upward 3 to 4 °C (5 to 7 °F). The inverse will be true if a test is conducted with a 50/50 ethylene glycol-water mixture coolant base when the engine manufacturer specifies water as the test coolant medium. Increased EOTD adjustments for coolant type may be required in a cooling system where the coolant velocity through the radiator tubes is extremely low.

8.1.3 FUEL RATE VARIATION—When the test is conducted at a fuel rate different than the specified value, the EOTD should be corrected (see Equation 4).

$$EOTD_{corr} = EOTD_{test}(\text{Specified Fuel Rate/Test Fuel Rate}) \quad \text{(Eq. 4)}$$

8.1.4 AMBIENT AIR TEMPERATURES—Most facilities provide control of the ambient air temperatures in the 27 to 38 °C (80 to 100 °F) range. Ordinarily in this range, no adjustment to the resulting EOTD is required. When the facility's ambient air temperature is below 27 °C (80 °F), the calculated EOTD is adjusted upward 0.5 to 1 °C (1 to 2 °F) for each 10-degree deviation in ambient temperature. Conversely, when the facility's ambient air temperature is above 38 °C (100 °F), the calculation EOTD is adjusted downward 0.5 to 1 °C (1 to 2 °F) for each 10-degree deviation in ambient temperature.

8.1.5 RAM AIR—In general, the EOTD decreases with increasing ram air velocity. Consequently, facilities without ram air capacity will produce an incorrect EOTD. Typically, a 2 to 4 °C (4 to 8 °F) change in EOTD will occur for a 24 km/h (15 mph) change in ram air velocity. Above 30 to 40 km/h (20 to 25 mph), the EOTD change is not predictable.

8.1.6 AIR CONDITIONING—Some test conditions (low ambient) will require the A/C unit to be off in order to prevent the compressor from cycling and radiator mounted condenser core is installed but the air conditioning unit is not operating during the test, the EOTD should be increased by 2 to 3 °C (4 to 6 °F). When no radiator mounted condenser core is installed on the test unit but will be offered on the model being tested, the EOTD should be increased by 4.0 °C (7 °F).

***9. Analysis of Cooling Tests*—**The analysis of a cooling system test presumes that the desired system performance requirements have been previously determined and that the test procedures have been properly followed; faults in these areas are not considered. The analysis of a cooling system test often provides information which can be used to improve the system's (a) performance and (b) production cost effectiveness.

9.1 Radiator Air Temperature—The difference between the air entering and leaving the radiator is affected by the performance of all the components in the entire system; the radiator core, fan and shroud, their enclosure, and the vehicle itself. If each of the cooling system components performs at its potential, unencumbered by excessive vehicle restrictions, the difference between core inlet and outlet air temperature is usually in the range of 22 to 33 °C (40 to 60 °F). Deviations (up and down) are indicative of low or high air flow, respectively. Whether or not this should be considered normal and/or expected should be determined through analysis with the heat exchanger manufacturer. It is not meant to imply failure to meet the predetermined system performance criteria, but it does mean that there may be potential for improvement in either the EOTD and/or the effectiveness of the system.

9.1.1 CAUSE OF HIGH RADIATOR AIR TEMPERATURE RISE

9.1.1.1 High Core Air Restriction

a. Change—Decrease fins per inch (core fin density)
b. Potential Result—Optimized performance, increased EOTD, lowered fin fouling tendencies, different first cost, lowered operating costs, larger core size requirement

9.1.1.2 Inadequate Air Flow Performance

a. Change—Increase fan speed
b. Potential Result—Decreased EOTD, increased fan horsepower, possible increase in first cost, increased operating cost, increased noise
c. Change—Increase fan diameter, number of blades and/or projected width
d. Potential Result—Decreased EOTD, increased fan horsepower, possible increase in first cost and increased operating cost, increased noise
e. Change—Fan and shroud package

    1. No shroud to ring shroud, ring to box, box to venturi

f. Potential Result—Decreased EOTD, increased first cost
g. Change—Fan to shroud relationship

    1. Decrease tip clearance

h. Potential Result—Decreased EOTD, fan shroud interference during severe frame racking maneuvers
i. Change—Fan penetration into the shroud—increase penetration if fan is in axial flow (low chassis restriction), decrease penetration if fan is in radial flow (high chassis restriction)
j. Potential Result—Decreased EOTD, different sound levels

9.1.1.3 Air Recirculation

a. Change—Add baffles and/or seals around radiator
b. Potential Result—Decrease underhood recirculation, increased first cost, improved EOTD
c. Change—Reduce air flow restriction by changing grill, bumper, etc.
d. Potential Result—Increased air flow

9.1.2 CAUSE OF LOW RADIATOR AIR SIDE TEMPERATURE RISE—A low air temperature rise across the core is caused by the inverse of the previous and generally provides opportunities to effect savings for the engine/vehicle manufacturer and/or the end product user.

9.2 Radiator Coolant Temperature—The difference between the coolant entering the radiator and that of the coolant leaving the radiator core is usually in the range of 4 to 8 °C (7 to 14 °F). It is equal to the temperature rise across the engine if no bypass system permits part of the coolant to recirculate without passing through the radiator core. If a substantial portion of the engine coolant is bypassing the core, improved cooling may result from a change which will decrease the bypassed flow, i.e., full blocking bypass thermostat in place of a partial or non-blocking thermostat. In some instances it will be possible to install a heater valve that can be closed in warm weather. Other factors relating to the transfer of heat from the coolant to the core, such as core tube velocity and proper distribution of the coolant through all core tubes, are beyond the scope of this analysis; they should be reviewed with the radiator manufacturer.