SURFACE VEHICLE RECOMMENDED PRACTICE

J1393™ FEB2023

Issued 1984-06
Reaffirmed 1999-02
Revised 2023-02

Superseding J1393 DEC2017

Heavy-Duty Vehicle Cooling Test Procedures

RATIONALE

Updated for content and clarity during Five-Year Review.

1. SCOPE

The purpose of this SAE Recommended Practice is to establish a testing procedure to determine the performance capability of heavy-duty vehicle cooling systems to meet Original Equipment Manufacturer or end user thermal specifications to ensure long term reliable vehicle operations. The recommendations from the present document are intended for heavy-duty vehicles including, but not limited to, on- and off-highway trucks, buses, cranes, drill rigs, construction, forestry, and agricultural machines.

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 J631 Radiator Nomenclature

SAE J814 Coolants for Internal Combustion Engines

SAE J1004 Glossary of Engine Cooling System Terms

SAE J1468 Oil Cooler Application Testing and Nomenclature

SAE J1726 Charge Air Cooler Internal Cleanliness, Leakage, and Nomenclature

SAE J2914 Exhaust Gas Recirculation (EGR) Cooler Nomenclature and Application

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 ISO Publications

Copies of these documents are available online at https://webstore.ansi.org/.

ISO 7464 Earth-moving machinery - Method of test for the measurement of drawbar pull

3. DEFINITIONS

3.1 VEHICLE COOLING SYSTEM

A vehicle cooling system can consist of several heat exchangers, pumps, valves, fans, and other pertinent components. It is designed to dissipate heat generated by the operation of the powertrain to the ambient environment to ensure safe and reliable vehicle operations.

3.2 AMBIENT AIR TEMPERATURE

For lab conditions, the ambient air temperature should be measured at a specified distance, at least 2 m away from the vehicle being tested, in front of the cooling system inlet grille or screens and reported. For field conditions, the ambient air temperature should be measured near the test vehicle and its location relative to the test vehicle should be recorded.

3.3 EOTD - ENGINE OUTLET TEMPERATURE DIFFERENTIAL

The difference between the coolant temperature at the engine outlet and the ambient air temperature.

3.4 Terms Used by the Industry Related to EOTD

3.4.1 AIR-TO-BOIL (ATB)

The ambient air temperature (°C) at which the engine coolant at the radiator inlet reaches its boiling point. The coolant boiling point is a function of the absolute pressure and the characteristics of the coolant. However, this term is also commonly used without consideration for the absolute pressure or the coolant characteristics. In the case of an open radiator at sea level pressure with water as coolant, a boiling point of 100 °C is assumed.

3.4.1.1 ATB = 100 °C – engine coolant outlet temperature + ambient air temperature.

3.4.2 LIMITING AMBIENT TEMPERATURE (LAT)

The ambient air temperature at which the engine coolant outlet temperature reaches the maximum allowable temperature.

3.4.2.1 LAT = Maximum engine coolant outlet temperature – engine coolant outlet temperature + ambient air temperature.

3.4.3 AMBIENT CAPABILITY

Similar to LAT (3.4.2) but refers to an ambient air temperature at which any of the fluids being cooled exceeds its design temperature limit under a specified operating cycle.

3.4.4 AIR-TO-REDLINE (ATR)

The ambient air temperature at which the engine coolant outlet temperature reaches the coolant overheat warning temperature.

3.4.4.1 ATR = Coolant overheat activation temperature – engine coolant outlet temperature + ambient air temperature.

3.4.5 AMBIENT DESIGN TEMPERATURES (ADT)

The ambient air temperature at which each fluid being cooled in the cooling system reaches its design temperature limit under specific operating conditions related to the equipment's application.

3.4.5.1 ADT = Fluid design temperature limit – max fluid temperature in system + ambient air temperature.

3.4.6 TOP TANK TEMPERATURE DIFFERENTIAL (TTTD, also known as Top Tank Differential, TTD)

The difference between the coolant temperature at the radiator top tank and ambient air temperature. For a cross flow radiator, this would be the difference between the radiator inlet temperature and ambient air temperature.

3.4.7 AIR-TO-WATER (ATW)

The temperature differential between ambient air and engine outlet. The terminology assumes water as the coolant.

3.4.8 INTAKE MANIFOLD TEMPERATURE DIFFERENTIAL (IMTD)

The difference between the temperatures of the air in the intake manifold inlet and the ambient air. For applications with EGR, the intake manifold temperature may be specified before or after the EGR mix location.

3.4.9 CHARGE AIR COOLER (CAC) OUTLET TO AMBIENT

The difference between the CAC outlet temperature and the ambient air temperature.

3.4.10 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 3.4.10.1.

3.4.10.1 CAC System Effectiveness = (Turbocharger outlet temperature – Intake manifold temperature)/(Turbocharger outlet temperature - Ambient air temperature)

4. HEAVY-DUTY VEHICLE COOLING SYSTEM DESCRIPTION

One example of heavy-duty vehicle cooling systems is found in Figure 1. The key components may include low temperature radiators, high temperature radiators, fan assembly, pumps, CAC, surge tank, thermostat and other similar components depending on vehicles' specific requirements. The system as shown in Figure 1 comprises an engine cooling loop that circulates coolant through a high temperature radiator to dissipate heat generated in the engine, and a charge air cooling loop that circulates coolant first through a low temperature radiator and then through a coolant-to-air exchanger to cool pressurized air from the turbocharger before entering the engine combustion chamber.

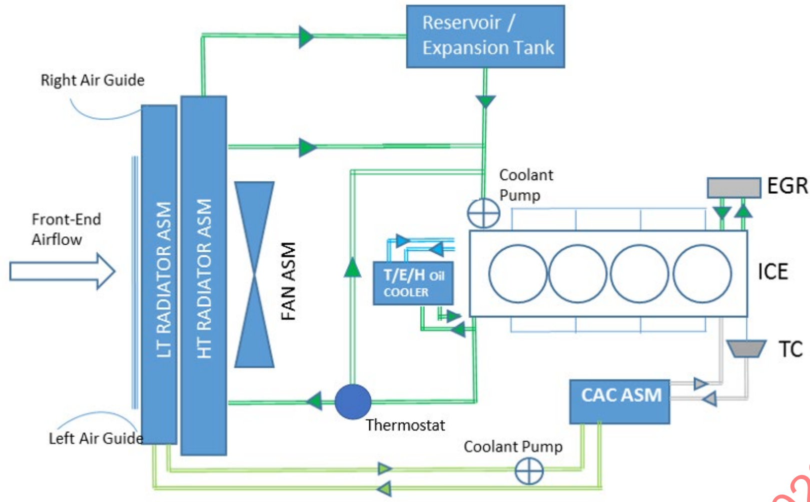

Figure 1 - Vehicle cooling system (T/E/H stands for transmission, engine, hydraulic)

4.1 Engine Cooling Module

An engine cooling module assembly is a subassembly of the vehicle cooling system designed for rapid installation in vehicle or equipment. Common heat exchangers found in cooling module assemblies include radiators, Charge Air Coolers (CACs), air conditioning condensers and transmission oil coolers. Other common cooling module assembly components include surge tanks, air shields, fan shrouds, mounting structure, hoses, and clamps. The modules are typically installed in the front or rear of vehicles and in a number of equipment orientations.

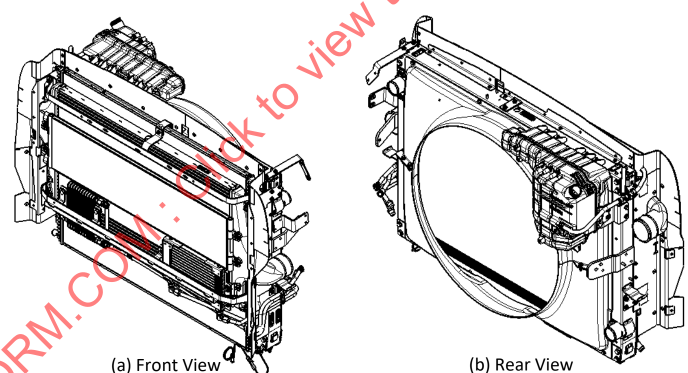

Figure 2 - Engine cooling module

4.2 Turbocharger

A turbocharger (Figure 3) provides forced air induction to the engine to improve engine efficiency as well as power density.

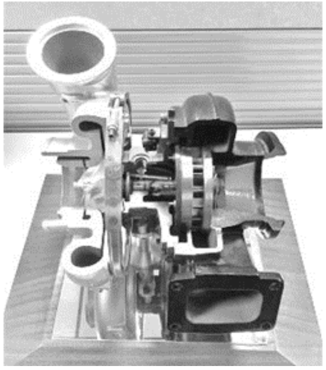

Figure 3 - Turbocharger cut-away view

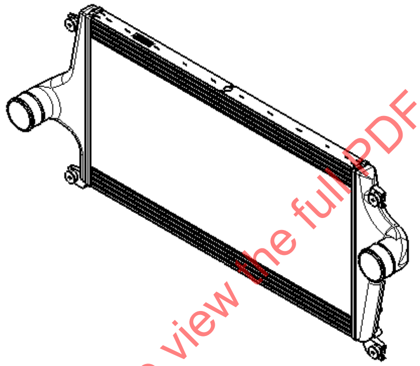

Figure 4 - Charge air cooler

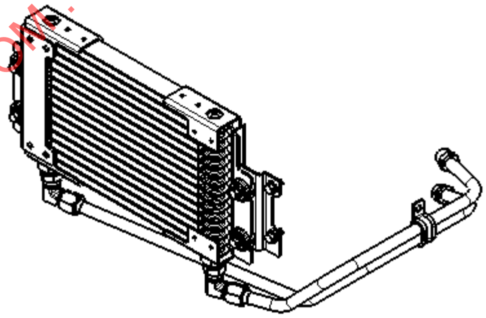

Figure 5 - Oil cooler

4.3 Charge Air Cooler

A charge air cooler (Figure 4) is an intercooler between the turbocharger and the engine intake manifold used to provide cooler air to the engine combustion chamber to improve engine efficiency. Charge air cooler can be an air-air heat exchanger or air-coolant heat exchanger.

4.4 Coolant Pump

A coolant pump provides the pressure head necessary to circulate coolant through the coolant loop components. Depending on the complexity of the vehicle cooling system, multiple circulation loops may exist which would require several coolant pumps to operate.

4.5 Oil Coolers

Oil coolers (Figure 5) may be used for automatic transmission fluid, hydraulic system oil, retarder system fluid, and engine oil. Oil coolers can be an oil-air heat exchanger or oil-coolant heat exchanger.

5. FACILITY REQUIREMENTS

5.1 Laboratory facilities should include the following:

5.1.1 Power Absorbing Device

A chassis or drivetrain dynamometer capable of absorbing rated horsepower and peak torque of the engine/vehicle.

5.1.2 Cooling Air

Constant air velocity and air temperature to the face of the cooling module within the range recommended by the vehicle manufacturer or the engine manufacturer.

5.1.3 Instrumentation

Ability to measure the required test data and test conditions with sufficient accuracy and repeatability. If the use of a controlled laboratory is not feasible, the test vehicle should be evaluated in an outside test course as described in 5.2. Instrumentation similar to that used in the laboratory is still required.

5.2 Field Testing Requirement

5.2.1 In the case of large construction machinery too large for testing on a chassis or drivetrain dynamometer, power absorption can be created using a drag sled test, running an appropriate high-severity duty cycle for the machine, or both. Multiple cycles may be specified for cooling tests, as different cycles may be the more high-severity duty cycle for engine, transmission, and hydraulic systems. Operating conditions should be carefully considered and tailored to meet vehicle requirements that maintain vehicle reliability and are cost effective.

6. TEST PREPARATION AND SET UP

6.1 Engine and Vehicle

6.1.1 It is preferable to perform tests at ambient air temperatures between 27 °C and 46 °C. Avoid performing cooling tests if the ambient air temperature is below 18 °C. This will minimize the effects of changes in air density.

6.1.2 For field tests of off-highway vehicles, it is preferable to test at wind speeds below 10 km/h unless wind is 90 degrees to the test course.

6.1.3 Prior to start of the test, the machine shall be inspected to assure that:

6.1.3.1 It is serviced as specified by manufacturer.

6.1.3.2 It delivers specified power. This can be checked by monitoring fuel consumption, turbocharger outlet temperature and pressure, or application of ISO 7464:1983 or other suitable means.

6.1.3.3 All items directly related to the cooling system performance, such as: fan speed, fan belt adjustment, fan to core spacing, air recirculation baffling or air recirculation shields, coolant and other fluid levels, radiator pressure cap, etc. are properly adjusted and the heat exchangers are clean inside and out, and the fins are straight and in good condition.

6.1.3.4 For subsystem lab test conditions, i.e., engine dyno tests, engine restrictions such as intake and exhaust pressure drop are representative of full vehicle or target values.

6.1.4 The engine coolant thermostats should be blocked to the manufacturer's specified opening for the maximum design operating ambient air temperature condition.

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

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

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

6.1.8 Cabin heater fan should be "off" if different from air conditioning fan.

6.1.9 Block the coolant flow through the cabin heater hoses at engine without affecting the flow of other auxiliary coolant circuits if equipped.

6.1.10 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.

6.1.11 Engine coolant should be 50/50 glycol solution concentration by volume (refer to SAE J814) or 100% water as required by the engine manufacturer's test procedure. For pure water, test procedure may specify pressure per engine cooling spec of OEM. Additionally, some manufacturers keep the top tank open during tests with either fluid.

6.1.12 Follow manufacturer's testing guidelines to ensure EGR system is behaving as-required for cooling system testing. If no requirements are given, then the EGR system should be locked in a full flow state where there is max heat rejection to cooling system.

6.1.13 Operating modes for hybrid, electric, or fuel cell subsystems must be considered. If a mode is available which is worst case for heat rejection, it must be selected unless otherwise documented and agreed upon.

6.2 Instrumentation and Data Log

6.2.1 Required Test Parameters (Table 1)

Table 1 - Required test parameters

Symbol	Description	Unit	Note
δt	Time Interval	s	
$ERPM$	Engine Speed	rpm	Revolutions Per Minute.
$FRPM$	Fan Speed	rpm	Revolutions Per Minute.
$\dot{m}_{fuel}$	Fuel Flow Rate	kg/s	
T_{fuel}	Fuel Temperature	°C	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.
T_{amb}	Ambient Temperature	°C	Shade thermometers and thermocouples from sun or other sources of non-pertinent radiated heat.
RH_{amb}	Ambient Relative Humidity	%	
H	Altitude	m	
P_{baro}	Barometric Pressure	kPa	Absolute pressure.
V_{air}	Ram Air Speed	m/s	For on-highway vehicles, velocity of ram air measured 1.0 m 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).
T_{air}	Ram Air Temperature	°C	For on-highway vehicles, temperature of ram air measured 1.0 m 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).
$T_{clnt,EO}$	Engine Outlet Coolant Temperature	°C	Coolant temperature at engine outlet to the radiator. This temperature should be measured as close to the engine coolant outlet as reasonably possible.
$T_{clnt,EI}$	Engine Inlet Coolant Temperature	°C	Coolant temperature at engine inlet from the radiator. This temperature should be measured as close to the engine coolant inlet as reasonably possible.
$\dot{V}_{clnt}$	Volumetric Coolant Flow Rate	l/min	Coolant flow rate at engine outlet to radiator.
$T_{oil,E}$	Engine Oil Temperature	°C	Oil temperature of engine for monitoring stabilization and abort purposes.
$P_{oil,E}$	Engine Oil Pressure	kPa	Oil pressure of engine for monitoring stabilization and abort purposes.
$T_{air,AI}$	Combustion Air Temperature (1)	°C	Combustion air temperature at entrance to air induction system.
$T_{air,ACBE}$	Combustion Air Temperature (2)	°C	Combustion air temperature in air cleaner before element.
$T_{air,TI}$	Combustion Air Temperature (3)	°C	Combustion air temperature at turbo inlet for turbocharged engines.
$T_{air,IMI}$	Combustion Air Temperature (4)	°C	Combustion air temperature at intake manifold inlet or in the manifold.
$T_{air,RI}$	Radiator Inlet Air Temperature	°C	At least four locations determined by splitting the core into equal areas.
$T_{air,RO}$	Radiator Outlet Air Temperature	°C	At least four locations determined by splitting the core into equal areas.
$T_{air,CACI}$	CAC Cooling Air Inlet Temperature	°C	At least four locations determined by splitting the core into equal areas.
$T_{air,CACO}$	CAC Cooling Air Outlet Temperature	°C	At least four locations determined by splitting the core into equal areas.
$T_{clnt,CACI}$	Liquid CAC Coolant Inlet Temperature	°C	Measure if equipped with LCAC.
$T_{clnt,CACO}$	Liquid CAC Coolant Outlet Temperature	°C	Measure if equipped with LCAC.

6.2.1.1 Optional test information for the analysis of the cooling system may be obtained by measuring the following:

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

6.2.1.3 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.

6.2.1.4 Axial distance fan projects out of shroud at top, at bottom, and at both sides. This is required for fan penetration into the shroud.

6.2.1.5 Distance between fan and radiator core at top, at bottom, and at both sides. This is to determine the proximity of the fan to the core.

6.2.1.6 Distance between fan and 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.

6.2.2 Optional Data to Record (Table 2)

Table 2 - Optional data to record

Symbol	Description	Unit	Note
S	Ground Speed	km/h	
G	Transmission Gear		
PWR_{dyno}	Dynamometer Power	kW	
$T_{lube,AX}$	Axle Lubricant Temperature	°C	
$T_{oil,TR}$	Transmission Oil Temperature	°C	
$P_{oil,TR}$	Transmission Oil Pressure	kPa	
$T_{oil,HS}$	Hydraulic System Oil Temperature	°C	
$P_{oil,HS}$	Hydraulic System Oil Pressure	kPa	
$P_{clnt,PI}$	Coolant Pump Inlet Pressure	kPa	
$P_{clnt,PO}$	Coolant Pump Outlet Pressure	kPa	
$T_{air,EC}$	Engine Compartment Temperature	°C	
$T_{exh,TO}$	Exhaust Gas Temperature at the Turbo Outlet	°C	If equipped.
$P_{air,ACE}$	Air Cleaner Exit Pressure	Pa	Measured at the location provided for the air cleaner restriction gage.
$P_{air,TO}$	Turbo Outlet Pressure	Pa	If equipped.
$P_{air,IM}$	Intake Manifold Pressure	Pa	Turbocharged Engines Only. A port location in the intake manifold should be specified by the engine manufacturer if accurate data is critical.
$P_{air,CO}$	Compressor Outlet Pressure	Pa	

7. PROCEDURE

7.1 For Lab Conditions

7.1.1 For mobile equipment, such as heavy-duty vehicles, adjust the ram air velocity with engine off to maintain the test speed specified by the engine manufacturer, for example, 24 km/h.