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Document Name: SAE J1937: Recommended Practice for Engine Testing with Low Temperature Charge Air Cooler Systems in a Dynamometer Test Cell

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ENGINE TESTING WITH LOW TEMPERATURE CHARGE AIR COOLER SYSTEMS IN A DYNAMOMETER TEST CELL—SAE J1937 NOV89

SAE Recommended Practice

Report of the Diesel Emissions Standards Committee approved November 1989.

1. Scope—The methods presented in this document apply to the controlled testing of low temperature charge, air cooled, heavy duty diesel engines. This document encompasses the following main sections:

a. Definitions of pertinent parameters.
b. Vehicle testing to determine typical values for these parameters.
c. Description of the setup and operation of the test cell system.
d. Validation testing of the test cell system.

While not covered in this document, computer modeling of the vehicle engine cooler system is recognized as a valid tool to determine cooler system performance and could be utilized to supplement the testing described. However, adequate in-vehicle testing should be performed to validate the model before it is used for the purposes outlined.

The procedure makes references to test cycles that are prescribed by the United States Environmental Protection Agency (US EPA) and are contained in the Code of Federal Regulations. The existence of other international test cycles, which can be used for validation testing, is acknowledged.

2. Purpose—The primary purpose of this document is to aid in the setup and evaluation of a low temperature charge air cooler system for use with heavy duty diesel engines (HDDE) in dynamometer test cells. These charge air cooler systems typically provide cooled, charge air temperatures lower than jacket water after cooled systems but above ambient temperature. Examples of low temperature charge air cooler systems include air-to-air after cooled and low flow coolant after cooled systems. While this document addresses emissions evaluation of such engines, it is not limited to that use.

3. Definitions of Terminology

3.1 Heated Charge Air—Engine charge air that has been heated by compression in a turbocharger(s) or supercharger(s).

3.2 Cooling Medium—The fluid, usually air or water, used to cool the heated engine charge air.

3.3 Cooled Charge Air Temperature—The temperature of the cooled charge air entering the engine (commonly referred to as "intake manifold" temperature). This temperature may differ significantly between the test cell and the vehicle due to underhood heating. Engine inlet air temperature rise of 8 to 10°C from the air cleaner to the turbocharger(s) or supercharger(s) and cooled charge air temperature rise of 3 to 5°C from the engine charge air cooler to the engine inlet are typical in the vehicle. Piping length should be minimized and properly routed to minimize this temperature rise.

3.4 Engine Charge Air Cooler—The heat exchanger located in the charge air path between the engine turbocharger(s) or supercharger(s) and the engine cylinders. It reduces the charge air temperature by transferring heat from the charge air to a cooling medium.

3.5 Cooled Charge Air—Engine charge air that has been cooled by passing through the engine charge air cooler.

3.6 Engine Radiator—The heat exchanger used for engine cooling. In some systems, the engine radiator(s) also provides coolant to the engine charge air cooler.

3.7 Engine Charge Air Cooler System Volume—The volume of the intake air system from the turbocharger outlet to the engine inlet. This volume includes the piping to and from the engine charge air cooler and the charge air cooler itself.

3.8 Test Cell Cooler System—The system of heat exchangers and related hardware in the test cell used to cool the charge air to the engine.

3.9 Rated Load Set Point Temperature—The cooled charge air temperature with the engine operating and stabilized at rated speed and load at a 25°C ambient temperature. This set point can be established through vehicle on-road testing, full load vehicle testing on a chassis dyno, from engine manufacturer specifications for the intended application, or from computer modeling of the cooler system.

3.10 Engine Charge Air Cooler System Thermal Response Time—Time to reach 85% of the cooled charge air temperature difference between low idle and rated engine speed and load following a rapid acceleration between these two operating conditions.

3.11 Engine Charge Air Cooler System Pressure Drop—The charge air pressure differential measured between the turbocharger or supercharger outlet and the engine inlet. These pressure measurements are taken with the engine operating at rated engine speed and load. A static pressure measurement taken at each location will normally provide an adequate measurement of pressure differential and is a much simpler measurement than the total pressure at each location. Care should be taken to make the measurement in a location without bends and piping size changes.

3.12 Transient Emissions Test—The test procedure prescribed by the US EPA for emissions testing of HDDE. The test is performed in an engine test cell and requires the use of a dynamometer with motoring capability. The test procedures are described in the Code of Federal Regulations (CFR) Title 40, Part 86, Subpart N.

3.13 Transient Test Cycle—The 20 min test cycle consisting of second-by-second listings of normalized speed and torque values. A listing of the individual points is contained in CFR Title 40, Part 86, Appendix I (f)(2).

3.14 Federal Smoke Test—The test procedure prescribed by the US EPA for smoke opacity testing of HDDE. This test is performed in an engine test cell and is described in CFR Title 40, Part 86, Subpart I.

3.15 Heavy Duty Chassis Cycle—The test cycle prescribed by the US EPA for chassis dynamometer testing of heavy duty vehicles. The test schedule is contained in CFR Title 40, Part 86, Appendix I (d).

4. Important Engine Charge Air Cooler System Parameters

4.1 Cooled Charge Air Temperature—The most important parameter to be controlled by the test cell cooler system during engine testing is the cooled charge air temperature. The cooled charge air temperature has a strong effect on engine performance and emission levels, so this temperature must be controlled to levels typical of vehicle operation. This document describes a procedure to define the typical cooled charge air temperature levels (5.1) and to set up the test cell cooler system to achieve those levels during the EPA Transient Emission Test and Federal Smoke Test (6.2).

4.2 Engine Charge Air Cooler System Pressure Drop—The pressure drop in the engine charge air cooler system affects the pressure of the cooled charge air when it reaches the cylinders. This pressure drop affects the air/fuel ratio and could affect performance and emissions. Therefore, the test cell cooler system must have a charge air pressure drop representative of typical, installed vehicle charge air cooler systems.

4.3 Engine Charge Air Cooler System Thermal Response Time—Due to the highly transient nature of the EPA Transient Test Cycle and the effect of the cooled charge air temperature on emissions, it is necessary to ensure that the thermal response of the test cell cooler system is representative of the vehicle charge air cooler system. Caution must be exercised when using an air-to-water test cell cooler system to simulate a vehicle air-to-air system. Excessive water volume could result in a thermal response that is not representative of the vehicle air-to-air system.

4.4 Engine Charge Air Cooler System Volume—During transient engine operation, the charge air cooler system volume affects the instantaneous air/fuel ratio and could affect performance and emissions. It is, therefore, necessary to ensure that the test cell cooler system volume is representative of vehicle installations.

5. Vehicle Testing—Actual vehicle testing (or computer modeling of the vehicle cooler system using a valid model) should be conducted to determine values for the important engine charge air cooler system parameters. The vehicle used should be representative of a typical installation for the engine size and output being tested. The values generated for these charge air cooler system parameters are needed to validate the performance of the test cell cooler system. Generalized descriptions of typical vehicle charge air cooler systems are included in A.1.

During this vehicle testing, attention should be given to the temperature rise of the engine inlet air and cooled charge air due to underhood heating to ensure that they are not excessive.

5.1 Cooled Charge Air Temperature

5.1.1 The rated load set point temperature should be determined during operation at rated engine speed and load in the vehicle. This testing can be done on the road and/or on a chassis dynamometer if ram air representative of on-the-road operation can be provided. The hardware used (charge air cooler, radiator, cooling fan, etc.) should be representative of a typical installation meeting engine manufacturer application guidelines. The engine cooling fan drive should be fully engaged when determining the rated load set point temperature. The engine cooling medium used in the test cell should be the same as used in the vehicle testing (i.e., water or antifreeze).

5.1.2 On-road vehicle operation should also be performed to define a cooled, charge air temperature range for operating conditions typical of the transient cycle. Operating conditions should follow the time records of the EPA Heavy Duty Chassis Cycle or be characteristic of the three modes of the 20 min EPA Transient Cycle as listed below:

Vehicle speeds averaging 13 km/h	New York Nonfreeway
Vehicle speeds averaging 24 km/h	Los Angeles Nonfreeway
Vehicle speeds averaging 72 km/h	Los Angeles Freeway

Low idle periods of up to 2 min duration should also be included to duplicate the idle periods contained in the EPA Transient Test Cycle. The cooling fan should operate in the normal mode for this testing. The EPA Heavy Duty Chassis and Transient Test cycles are different from each other but should produce similar ranges of cooled charge air temperature.

5.1.3 It is recommended that these tests be run at an ambient temperature of 25°C ± 5 and results corrected to 25°C ambient. In this range, cooled charge air temperature can be corrected 1°C per 1°C ambient with adequate accuracy. Operation at ambient temperatures outside of this range should be limited to those temperatures whose results can be accurately extrapolated to 25°C ambient.

5.2 Engine Charge Air Cooler System Pressure Drop—Pressure drop across the engine charge air cooler system should be measured at rated engine speed and load in a variety of vehicles. This measurement can be made at the same time that the rated load set point is being measured.

5.3 Engine Charge Air Cooler System Thermal Response Time—Thermal response data can be obtained on a chassis dynamometer, during on-the-road testing with a loaded trailer or a dynamometer trailer, or from computer modeling of the vehicle cooler system. If on-the-road testing is performed, the trailer or dyno trailer used should provide a load that is typical for the vehicle being used. The engine cooling fan drive should be fully engaged for this testing.

The thermal response of the engine charge air cooler system is determined by a rapid acceleration from low idle to rated engine speed and load, until the cooled charge air temperature stabilizes. Gearing should be selected (or ram air provided) to result in road speeds in the vicinity of 48 to 72 km/h when the engine is at rated speed and load. The cooled charge air temperature history should be recorded over this time period for later comparison to test cell cooler system response.

If possible, this test should be run twice to establish the effect of a "cold" versus "hot" charge air cooler on thermal response. This can be easily accomplished by running back-to-back tests without allowing the engine to remain at low idle between tests.

6. Initial Test Cell Cooler System Set Points—This section describes the initial adjustment of the test cell cooler system parameters to approximate values obtained from vehicle testing. The same test cell cooler system should be used for both EPA Transient Emissions Test and Federal Smoke Test. The location of the cooled charge air pressure and temperature transducers should be the same for both the in-vehicle and the test cell dynamometer testing.

6.1 Various test cell systems are used by manufacturers to simulate vehicle charge air cooler systems. These can be classified into two general types depending on the cooling medium used to cool the heated charge air. A brief description of each type of test cell system is included in A.2.

6.2 Before EPA Transient Emissions or Federal Smoke testing is performed, operate the engine at rated speed and load and adjust the cooled charge air temperature to the rated load set point ±3°C (5.1.1). At the same time, the test cell cooler system pressure drop should be measured and adjusted, if necessary, to ±2 kPa of the pressure drop representative of vehicle charge air cooler systems.

For EPA Transient Emissions testing, these settings should be adjusted prior to running the maximum torque curve and should be used for transient emissions testing following forced or natural cool down. For Federal Smoke testing, these adjustments should be made during the 10 min warm-up prior to the first smoke cycle.

6.2.1 For test cell cooler systems using water as the charge air cooling medium (i.e., air-to-air (water bath), air-to-water, or water-to-water systems), the water flow and/or level is adjusted to obtain the rated load set point temperature. It is recommended that the water temperature used as the cooling medium be in the 20 to 30°C range. This will more easily provide a representative cooled charge air temperature at low idle with consideration given to underhood heating of the engine inlet air and cooled charge air.

6.2.2 For test cell cooler systems using air as the charge air cooling medium (i.e., air-to-air systems using engine driven or auxiliary cooling fans), airflow is controlled to obtain the rated load set point temperature. Due to the lack of vehicle ram air in the test cell, the cooled charge air temperature may exceed the rated load set point. Therefore, efforts should be made to maximize cooling airflow. It is recommended that the air used as the charge air cooling medium be controlled to 20 to 30°C. Again, this will more easily provide a representative charge air temperature at low idle with consideration given to underhood heating of the engine inlet air and cooled charge air.

6.2.3 For test cell cooler systems using the actual vehicle charge air cooler and piping, charge air cooler system pressure drop will be representative of that found in vehicle installations. Other test cell cooler systems may need means to adjust the engine charge air cooler system pressure drop.

7. Evaluation of Test Cell Cooler System Performance

7.1 Rated Engine Speed and Load—A check of rated load set point temperature and engine charge air cooler pressure drop should be made immediately following EPA Transient Emissions and Federal Smoke testing. With the engine operating at rated engine speed and load, cooled charge air temperature should match the rated load set point ±3°C and test cell cooler system pressure drop should match the pressure drop representative of vehicle charge air coolers within ±2 kPa.

7.2 Transient Emissions Test—The range of cooled charge air temperatures of the test cell cooler system observed during the EPA Transient Emissions test should fall within the range of cooled charge air temperatures observed during vehicle operation described in 5.1.2. In addition, the cooled charge air temperature during the low idle portion of the test shall not fall below 20°C.

If the range of cooled charge air temperatures of the test cell cooler system does not fall within the temperature range from vehicle testing, adjustment or modification to the test cell cooler system control should be made.

7.3 Federal Smoke Test—Cooled charge air temperature at low idle should meet the idle criteria in 7.2.

7.4 Thermal Response Test—The time to reach 85% of the temperature difference between low idle and rated speed and load should reasonably duplicate the response time observed from vehicle thermal response testing or from computer modeling of the vehicle cooler system. Thermal response data (A.3) obtained from a variety of manufacturers using several vehicles and types of test cell cooler systems show that the 85% point is typically reached in 1.5 to 3.5 min. Agreement within 1 min between the vehicle and test cell cooler system thermal response times should be used as a goal for developing a test cell cooler system.

8. Sensitivity Testing—Transient emissions and smoke levels of low temperature charge air cooled engines are sensitive to rated load set point temperature, cooling medium temperature, and charge air cooler system pressure drop. To minimize the effect of the test cell cooler system on test-to-test variability of emissions and smoke, limits are placed on these cooler system parameters (6.2 and 7.1). These limits are based on emission sensitivity testing conducted by various manufacturers on low temperature charge air cooled engines using test cell cooler systems. Since the data were obtained from a limited number of test cell cooler systems and engines, the effects shown below should be considered general in nature and should not be used to correct results of tests run outside of the suggested limits. A summary of this testing is included in A.4.

The data in Table 1 summarizes the effects that changes have on emissions and smoke in cooler system parameters. The percent of effect was calculated by dividing the change in measured emissions and smoke, resulting from the change in the parameter, by the mean of the initial and final emissions and smoke values. When testing was performed at more than two levels for each parameter, the change in emissions and smoke was determined from a least-squares-fit of the data. An average effect was calculated for each cooler system parameter when data was provided from more than one test cell cooler system or engine.

It should be noted that no effort was made to separate engine and instrument variability out of the following test results. In addition, no work was done to investigate the combined effect of changes in these parameters.

TABLE 1—SUMMARY OF EMISSIONS AND SMOKE SENSITIVITY

Emission	Range of Test Data	Average Effect of 3°C Increase in Rated Load Set Point	Effect of 2 kPa Increase in Cooler Pressure Drop	Average Effect of 5°C Increase in Cooling Medium Temperature
HC	0.32-0.89 g/bhp h	-0.7%	-2.0%	-1.8%
NOX	3.8-8.9 g/bhp h	+0.6%	-0.8%	+0.6%
PART	0.24-0.67 g/bhp h	-0.6%	+2.2%	+0.1%
ACC SMOKE	9.9-17.5% opacity	+0.2%	+3.3%	+3.0%
LUG SMOKE	0.7-13.6% opacity	+0.1%	+1.1%	-0.7%
PEAK SMOKE	13.8-43.5% opacity	+0.4%	+3.0%	+3.3%

Manufacturers may wish to determine the emission sensitivity of their test cell cooler systems. Suggested sensitivity test methods are included in A.4 for this purpose.

TEST CELL DATA

Engine Rating	Test Cell Cooler System	Cooling Medium	Cold Charge Air Temperature @ Idle	Rated Load Set Point Temperature	Thermal Response Time
317 Kw	Air to H_2O	30°C H_2O	35°C	48°C	2.4 min
298 Kw	Air to H_2O	25°C H_2O	33°C	46°C	3.5 min
261 Kw	Air to H_2O	30°C H_2O	30°C	44°C	2.2 min
231 Kw	Air to H_2O	30°C H_2O	32°C	41°C	3.0 min
168 Kw	Air to H_2O	32°C H_2O	34°C	45°C	4.0 min
179 Kw	Water bath	25°C H_2O	29°C	47°C	2.5 min
179 Kw	Water bath	25°C H_2O	29°C	43°C	5.0 min
224 Kw	Air to H_2O	27°C H_2O	29°C	43°C	2.3 min

VEHICLE DATA

Engine Rating	Vehicle System	Cooling Medium	Cold Charge Air Temperature @ Idle	Rated Load Set Point Temperature	Thermal Response Time
224 Kw	Air-to-air	25°C air	31°C	38°C	3.0 min
179 Kw	Air-to-air	13°C air	20°C	39°C	1.4 min
298 Kw	Low flow	-3°C air	69°C	47°C	1.5 min
298 Kw	Air-to-air	23°C air	26°C	35°C	3.0 min

9. General Comments

9.1 Engines tested for exhaust emissions using a test cell cooler system should be tested with all emission control devices installed and functioning. This includes any temperature controlled device operational over an ambient temperature range of 20 to 30°C or any other device that affects charge air cooler performance in the vehicle.

9.2 If an engine driven fan is used in the test cell cooler system, the fan drive should be fully engaged during all testing. Appropriate safety precautions, including fan guards, should be followed.

9.3 Care should be taken to avoid water leaks into the combustion air system when water is used as the charge air cooling medium. In addition, care should be taken to avoid condensation in the charge air system during conditions of high humidity and low cooling water temperature.

APPENDIX A

A1. Vehicle Charge Air Cooling Systems—Two types of charge air cooler systems currently used in heavy duty vehicles are described as follows:

A1.1 "Air-to-Air" Vehicle Charge Air Cooler System—(See Fig. A1). An air-to-air charge air cooler system is mounted in the flow path of the vehicle cooling air either upstream of (as shown) or along side the engine radiator. Heated, charge air enters the charge air cooler, is cooled by vehicle cooling air, and is directed to the engine inlet. The

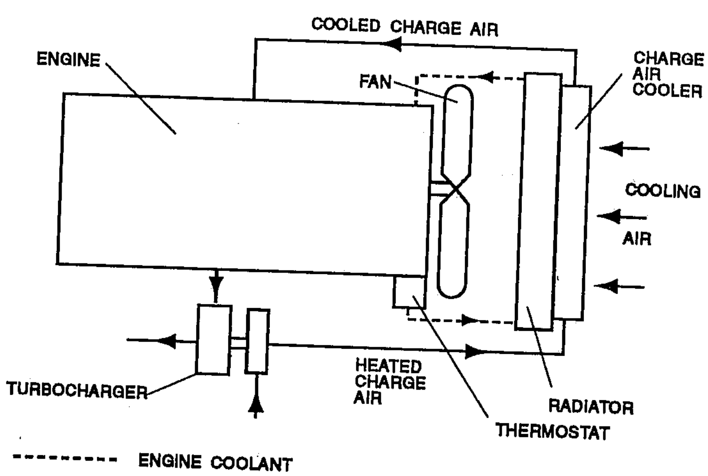

FIG. A1—"AIR-TO-AIR" VEHICLE CHARGE AIR COOLER SYSTEM temperature and flow rate of the cooling air depends on the ambient temperature, vehicle speed, and cooling fan speed.

A1.2 "Low Flow Coolant" Vehicle Charge Air Cooler System—(See Fig. A2). The charge air cooler is typically located in close proximity to the engine intake manifold. The heated charge air enters the charge air cooler, is cooled by low temperature coolant from the low flow engine radiator, and enters directly into the engine intake manifold. The temperature of the coolant is controlled by a system thermostat.

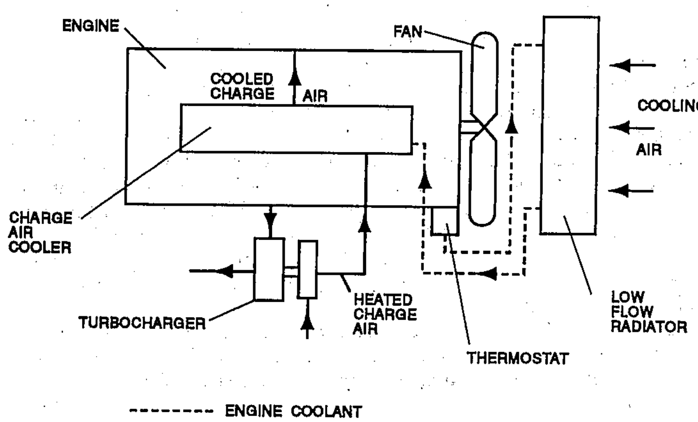

FIG. A2—"LOW FLOW COOLANT" VEHICLE CHARGE AIR COOLER SYSTEM

A2. Test Cell Charge Air Cooler Systems—Five types of test cell charge air cooler systems that are currently in use are described as follows. For test cell systems where the engine coolant is cooled by a test cell heat exchanger system, the engine coolant lines are not shown.

A2.1 "Water-to-Water" Test Cell Charge Air Cooler System—(See Fig. A3). This system is used to simulate the "low flow coolant" vehicle charge air cooler system. A water-to-water heat exchanger is used in place of the low flow radiator to control the engine coolant inlet and outlet temperatures. The engine coolant and cooled, charge air temperatures are adjusted to the rated load set point values. During EPA Transient Emissions and Federal Smoke testing, the temperature of the coolant to the charge air cooler is controlled by the engine thermostat.

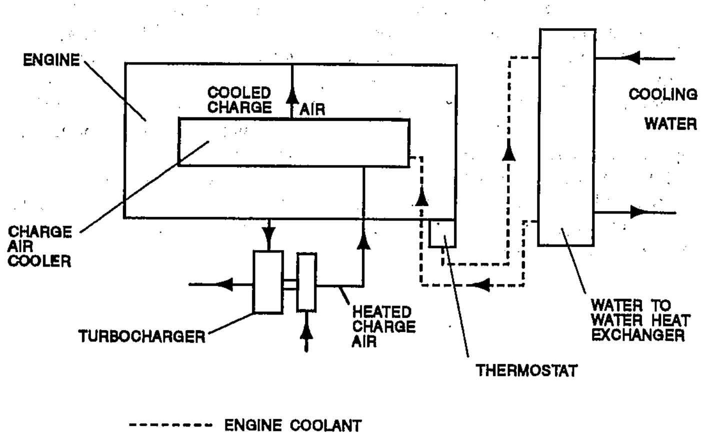

FIG. A3—"WATER-TO-WATER" TEST CELL CHARGE AIR COOLER SYSTEM

A2.2 "Air-to-Water" Test Cell Charge Air Cooler System—(See Fig. A4). This system uses an air-to-water heat exchanger to cool the heated, charge air in place of the "air-to-air" vehicle charge air cooler system. The heat exchanger is sized to handle the required charge air heat load and the charge air cooler system volume is sized to approximate the vehicle charge air cooler system volume. The cooling water flow is adjusted to obtain the rated load set point temperature.

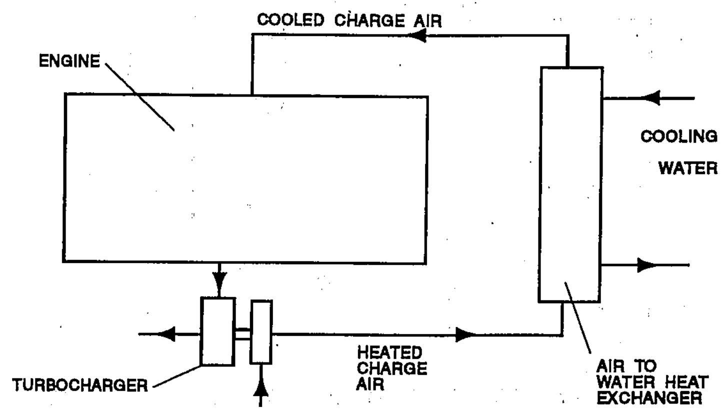

FIG. A4—"AIR-TO-WATER" TEST CELL CHARGE AIR COOLER SYSTEM

A2.3 "Air-to-Air (Water Bath)" Test Cell Charge Air Cooler System—(See Fig. A5). This system uses the vehicle charge air cooler submerged in a water tank in place of the "air-to-air" vehicle charge air cooler system. The heated, charge air is cooled by the surrounding water as the charge air passes through the charge air cooler. The temperature and/or flow of the water through the tank are adjusted to obtain the rated load set point temperature. In some cases, the water level is also adjusted to control the cooled charge air temperature at low idle.

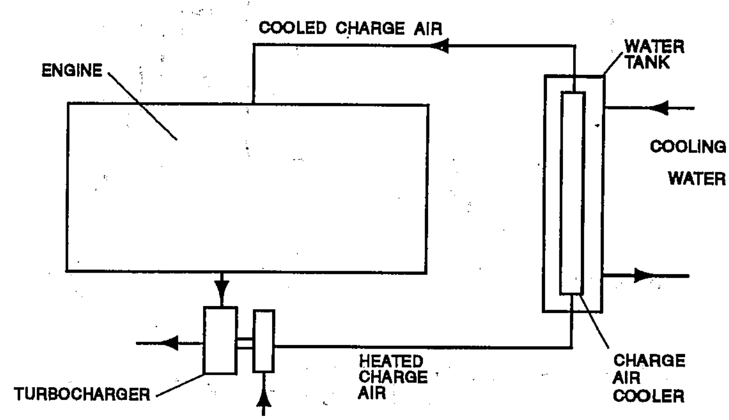

FIG. A5—"AIR-TO-AIR (WATER BATH)" TEST CELL CHARGE AIR COOLER SYSTEM

A2.4 "Air-to-Air (Engine Driven Fan)" Test Cell Charge Air Cooler System—(See Fig. A6). This system uses the vehicle charge air cooler and engine driven fan in the test cell. The heated charge air is cooled by passing the cooling air through the charge air cooler. This test cell system requires a test cell with sufficient ventilation to accommodate the cooling airflow and heat load.

Since the ram air effect is not generally available in the test cell, cooling airflow must be very high to avoid exceeding the rated load set point temperature.

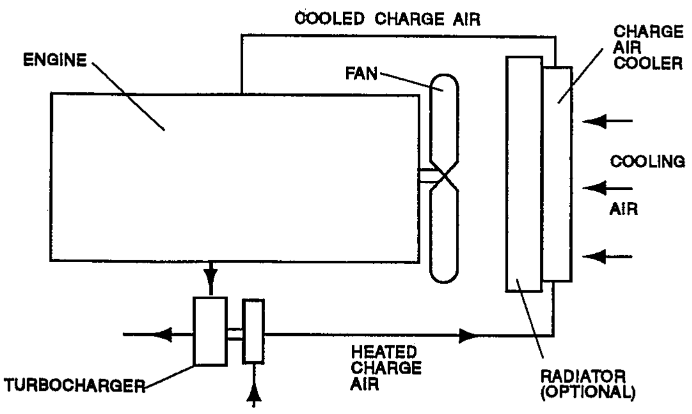

FIG. A6—"AIR-TO-AIR (ENGINE DRIVEN FAN)" TEST CELL CHARGE AIR COOLER SYSTEM

A2.5 "Air-to-Air (Auxiliary Fan)" Test Cell Charge Air Cooler System—(See Fig. A7). This system is similar to the system described in A.2.4 except that an auxiliary cooling fan is used in place of the engine driven fan. The auxiliary fan speed is proportional to engine speed.

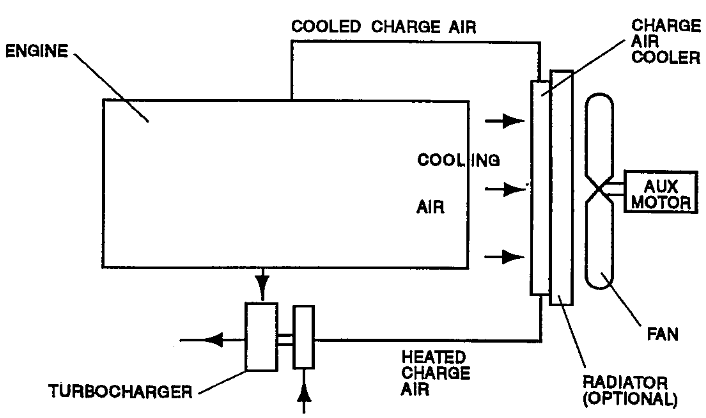

FIG. A7—"AIR-TO-AIR (AUXILIARY FAN)" TEST CELL CHARGE AIR COOLER SYSTEM

A3. Engine Charge Air Cooler Thermal Response—Thermal response data for rapid accelerations from idle to rated engine speed and load are summarized. Time to reach 85% of the cooled charged air temperature difference between low idle and rated engine speed and load was determined from cooled charge air temperature data recorded during these tests. The data were obtained from both the engine test cell and the vehicle tests.

A4. Sensitivity Testing—This section describes emissions and smoke sensitivity test procedures and presents test results for different test cell cooler system designs used by several engine manufacturers. The method used for calculating the average effect of each cooler system parameter on emissions and smoke is described in Section 8.

A4.1 Cooling Medium Temperature—A minimum of three EPA Transient Emissions and Federal Smoke tests should be run at each of three temperatures that cover the range of expected cooling medium temperatures. Typically, cooling medium temperatures 5°C above and below the normal temperature should be used to determine the sensitivity of emissions to cooling medium temperature. Cooling medium temperatures below 20°C are not recommended due to difficulty in maintaining a low idle charge air temperature above 20°C. Cooling medium temperatures above 30°C are generally insufficient to maintain the rated load set point temperature. The rated load set point temperature must remain constant for this testing to prevent any influence of rated load set point on the results. This requires adjusting the cooling medium flow as its temperature is changed to maintain a constant rated load set point temperature.

The data in Table A1 are examples of emissions and smoke sensitivity to cooling medium temperature. The data are the average of four engines run with air-to-water and air-to-air (water bath) test cell cooler systems.

TABLE A1—EFFECT OF COOLING MEDIUM TEMPERATURE ON EMISSIONS

Test Conditions
a. Constant Rated Load Set Point Temperature
b. 11 to 32°C Cooling Medium Temperature Range
c. US EPA Transient Emissions and Federal Smoke Cycles

Emission	Range of Test Data	Average Effect of 5°C Increase in Cooling Medium Temperature
HC	0.33-0.89 g/bhp h	-1.8%
NOX	4.8-8.8 g/bhp h	+0.6%
PART	0.25-0.50 g/bhp h	+0.1%
ACC SMOKE	9.9-13.1% opacity	+3.0%
LUG SMOKE	1.3-12.0% opacity	−0.7%
PEAK SMOKE	13.8-38.7% opacity	+3.3%

A4.2 Rated Load Set Point Temperature—A minimum of three EPA Transient Emission and Federal Smoke tests should be run at each of three rated load set point temperatures to determine the sensitivity of emissions and smoke to the rated load set point. These points should be chosen to be 10°C above and below the normal rated load set point. Some flow adjustment of the cooling medium is required to obtain the high and low rated load set point temperatures.

The data in Table A2 are examples of emissions and smoke sensitivity to rated load set point temperature. The data are averages of data from four engines run with an air-to-water and air-to-air (water bath) test cell cooler systems.

TABLE A2—EFFECT OF RATED LOAD SET POINT TEMPERATURE ON EMISSIONS

Test Conditions
a. Constant Cooling Medium Temperature
b. 25 to 65°C Rated Load Set Point Temperature Range
c. US EPA Transient Emissions and Federal Smoke Cycles

Emission	Range of Test Data	Average Effect of 3°C Increase in Rated Load Set Point Temperature
HC	0.32-0.63 g/bhp h	-0.7%
NOX	3.8-8.9 g/bhp h	+0.6%
PART	0.24-0.67 g/bhp h	-0.6%
ACC SMOKE	10-12.2% opacity	+0.2%
LUG SMOKE	0.7-13.6% opacity	+0.1%
PEAK SMOKE	16.8-41% opacity	+0.4%

A4.3 Charge Air Cooler System Pressure Drop—A minimum of three EPA Transient Emissions and Federal Smoke tests should be run to document the sensitivity of emissions and performance to the total pressure drop across the charge air cooler system. The pressure drop value is measured and adjusted at the rated speed and load condition. It is recommended that this testing be carried out at the design point and at two additional values of charge air cooler system pressure drop, typically ±5 kPa from the design point value.

The data in Table A3 are examples of emissions and smoke sensitivity to charge air cooler system pressure drop for a medium duty engine (179 BKW) using an air-to-air (water bath) test cell cooler system.

TABLE A3—EFFECT OF ENGINE CHARGE AIR COOLER SYSTEM PRESSURE DROP ON EMISSIONS

Test Conditions
a. Constant Cooling Medium Temperature
b. Constant Rated Load Set Point Temperature
c. 7 to 17 kPa Cooler System Pressure Drop Range
d. US EPA Transient Emissions and Federal Smoke Cycles

Emission	Range of Test Data	Effect of 2 kPa Increase in Cooler System Pressure Drop
HC	0.56-0.65 g/bhp h	-2.0%
NOX	6.9-7.8 g/bhp h	-0.8%
PART	0.35-0.39 g/bhp h	+2.2%
ACC SMOKE	14-17.3% opacity	+3.3%
LUG SMOKE	3.1-4.0% opacity	+1.1%
PEAK SMOKE	37-43.5% opacity	+3.0%