SURFACE VEHICLE RECOMMENDED PRACTICE

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Charge Air Cooler Internal Cleanliness, Leakage, and Nomenclature

RATIONALE

This document has been amended to include Air-to-Air Charge Air Cooler (CAC) internal chemical cleanliness as it applies to residual flux from Controlled Atmosphere Brazing (CAB). This chemical cleanliness requirement, which has been added, typically relates to only Natural Gas Engine applications that can be adversely affected by braze flux residue. The CAC debris cleanliness has been modified to include the maximum individual debris particle weight. Those requiring CAC cleanliness results should specify J1726 Chemical Internal Cleanliness, J1726 Debris Internal Cleanliness, or J1726 Chemical & Debris Internal Cleanliness.

1. SCOPE

This SAE Recommended Practice provides test methods and criteria for evaluating the internal cleanliness and air leakage for engine charge air coolers. This SAE Recommended Practice also provides nomenclature and terminology in common use for engine charge air coolers, related charge air cooling system components, and charge air cooling system operational performance parameters.

1.1 Description

An engine charge air cooler is a heat exchanger used to cool the charge air of an internal combustion engine after it has been compressed by an exhaust gas driven turbocharger or a mechanically or electrically driven blower (supercharger). The use of a charge air cooler offers increased engine horsepower output, reduced exhaust emission levels, and improved fuel economy through a more complete combustion process due to increased intake air density as a result of lower compressed air temperatures. Typical cooling media include the engine's coolant, ambient air, or an external coolant source.

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 J1542 Laboratory Testing of Vehicle and Industrial Heat Exchangers for Thermal Cycle Durability

SAE J1597 Laboratory Testing of Vehicle and Industrial Heat Exchangers for Pressure-Cycle Durability

SAE J1598 Laboratory Testing of Vehicle and Industrial Heat Exchangers for Durability Under Vibration-Induced Loading

2.2 Other Publications

2.2.1 ASTM International

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

ASTM D857 Standard Test Method for Aluminum in Water

ASTM D1193 Standard Specification for Reagent Water

ASTM D1976 Standard Test Method for Elements in Water by Inductively-Coupled Argon Plasma (ICP) Atomic Emission Spectroscopy

ASTM D4192 Standard Test Method for Potassium in Water by Atomic Absorption Spectrophotometry

ASTM D4327 Standard Test Method for Anions in Water by Suppressed Ion Chromatography

ASTM D4691 Standard Practice for Measuring Elements in Water by Flame Atomic Absorption Spectrophotometry

2.2.2 Technology & Maintenance Council

Available from Technology & Maintenance Council, 950 North Glebe Road, Suite 210, Arlington, VA 22203-4181, Telephone: 703-838-1763, www.tmc@trucking.org.

TMC Recommended Practice RP 331 Charge Air Cooler Integrity

3. CHARGE AIR COOLER CHEMICAL AND DEBRIS INTERNAL CLEANLINESS ACCEPTANCE CRITERIA

Completed CAC assemblies shall meet the internal cleanliness criteria as specified by the engine manufacturer. In the absence of engine manufacture criteria, the following guidelines are recommended:

Chemical Cleanliness (3.1 – 3.3) Typically Applies Only to Natural Gas Engines

3.1 Maximum Potassium Level ≤ 60 ppm

3.2 Maximum Fluoride Level ≤ 46 ppm

3.3 Maximum Aluminum Level ≤ 12 ppm

Debris Cleanliness (3.4 – 3.7)

3.4 Maximum Total Weight of Debris = 25.0 mg (8.82 x 10^{-4} oz) This is a recommendation based on a “typical” On-Highway CAC with a face area of 0.20 to 1.0 square meter and up to a 70 mm thickness. CAC units having a smaller size/volume will have proportionately lower recommended total debris weight while CAC units used for Off-Highway or Industrial Applications will have a proportionately higher value.

3.5 Maximum Individual Debris Particle Size = 3.175 mm (0.125 in)

3.6 Maximum Individual Debris Particle Area = 2.58 mm^2 (0.004 in^2)

3.7 Maximum Individual Debris Particle Weight = 1.4 mg (4.94 x 10^{-5}oz)

Particles for dimensional analysis include sand, scale, cleaning shot, machining chips, weld spatter, slag, or particles that can be reasonably handled/extracted in a laboratory environment. Specifically, particles having a specific gravity >1.0 should be scrutinized while those that are <1.0 may be discarded, or not analyzed.

4. CHARGE AIR COOLER CHEMICAL AND DEBRIS INTERNAL CLEANLINESS TEST METHODS

The apparatus and procedure for determining CAC chemical and debris internal cleanliness is described as follows:

4.1 Apparatus for chemical cleanliness

Laboratory Glassware

Laboratory Supplies

Ion Chromatograph (IC)

Atomic Absorption (AA) Spectrophotometer

4.2 Procedure for Determine Chemical Cleanliness

4.2.1 All laboratory glassware used for testing must be clean and triple rinsed with ASTM D1193 Type I reagent water.

4.2.2 Obtain clean and rinsed rubber stoppers to seal CAC so it is water tight.

4.2.3 Plug all CAC ports except the one highest in the unit under test.

4.2.4 Fill the CAC with Type I reagent water, tipping it back and forth to let air escape. Be careful to avoid any solution loss from inside the CAC.

4.2.5 Once the CAC is full of water, seal the last port and let the unit under test sit stationary at room temperature for eight (8) hours.

4.2.6 At the conclusion of eight (8) hours, carefully drain the CAC into a clean vessel that will hold the total internal volume of solution from the CAC.

4.2.7 Once all the solution is collected from the CAC in the vessel, stir the solution with a stir rod until it is sufficiently mixed.

4.2.8 With a clean sample bottle, remove approximately 100 milliliters of solution from the vessel for chemical analysis.

4.2.9 Using standard laboratory procedures outlined by ASTM in Section 2, REFERENCES, analyze the solution sample with an AA, or ICP and IC to determine the flux chemical element levels in ppm. Compare these results to the criteria provided above. External analytical laboratories can be used as resources dictate.

4.2.10 The report should include the following:

- Customer Part Number
- Manufacturer's Part Number
- Date of Manufacture
- Chemical Cleanliness Levels

4.3 Apparatus for debris cleanliness

5.0 μ Qualitative Grade Filter Paper

0.5 μ Membrane Filter Paper

Filtering Assembly

Vacuum Filtering Flask

Beakers

Reagent Grade Solvent, also known as Methanol. Note: Methanol is a highly volatile and flammable solvent and should be handled accordingly. Methanol is compatible with most metallic and non-metallic Charge Air Cooler component parts and assemblies. If possible, Charge Air Cooler component part compatibility with Methanol should be confirmed prior to testing.

Analytical Balance Sensitive to 0.1 mg

Drying Oven

Desiccator

Tweezers

Magnification Device with Scale

4.4 Procedure for determining debris cleanliness

4.4.1 All glassware and the test area used for determining CAC compliance with this document must be clean and free from debris.

4.4.2 Filter the selected test solvent through a 0.5 micron membrane filter paper. Replace with a new filter paper if total debris causes clogging.

4.4.3 Place a 5.0 micron qualitative grade filter paper in the drying oven at 100 °C (212 °F) for 15 min. Remove filter paper from drying oven and place in a desiccator to cool to 20 °C (68 °F). Remove filter paper from the desiccator and weigh it to the nearest 0.1 mg (3.5×10^{-6} oz) with an analytical balance. Record tare weight of filter paper as Wt0. Replace with a new filter paper if total debris causes clogging, results being additive.

4.4.4 Position the CAC so that the inlet and outlet portals are facing upwards. Pour a volume of filtered solvent equal to 40% of the total internal volume of the CAC into the CAC air inlet portal, and cap the air inlet and outlet portals.

4.4.5 Tip the CAC back and forth in such a manner that the inlet and outlet tanks are alternately filled with solvent. Repeat the back and forth tipping for 10 cycles to ensure that the solvent flushes all the internal surfaces. Tipping the CAC back and forth so that the solvent flows from one tank to the other and then back to the first tank is equal to 1 cycle.

4.4.6 Drain half of the solvent from the air outlet portal of the CAC into a beaker. Drain the other half of the solvent from the air inlet portal of the CAC into a beaker. Filter the solvent through the previously prepared and weighed 5.0 micron filter paper, which has been set up in the vacuum filtering assembly.

4.4.7 The spent filtrate can be used for future CAC testing after it has been filtered through a 0.5 micron filter paper.

4.4.8 Remove the filter paper from the filtering assembly and place it in the drying oven at 100 °C (212 °F) for 15 min. Remove the filter paper from the drying oven and place it in a desiccator to cool to 20 °C (68 °F). Remove the filter paper from the desiccator and weigh it to the nearest 0.1 mg (3.5 x 10-6 oz) with an analytical balance as Wte.

4.4.9 The dry weight of the filter paper with the debris residue (Wte) minus the tare weight of the filter paper (Wt0) equals the debris weight (Wtd). Compare the measured debris weight (Wtd) to the debris weight limit to determine if this requirement has been met.

4.4.10 Using the magnification device and its included optical scale, measure the maximum and minimum linear dimensions of the debris particles on the filter paper. Calculate the area of the debris particles. Compare the measured debris particle sizes to the debris size limit and compare the calculated debris particle areas to the debris particle area limit to determine if these requirements have been met.

4.4.11 The report should include the following:

- Customer Part Number
- Manufacturer's Part Number
- Date of Manufacture
- Debris Weight, Particle size and Particle Area Results

5. CHARGE AIR COOLER LEAKAGE

These sections describe the circumstances where small leaks in air-to-air charge air coolers are acceptable and describes test methods to measure these leaks. Brazed aluminum, air-to-air charge air coolers have been used since the early 1980's on many turbocharged Diesel engines. It is difficult to manufacture charge air coolers completely free of leaks, and Diesel engine performance is not significantly affected by slight charge air leaks. Consequently, most engine manufacturers publish allowable leak rates for charge air coolers.

6. CHARGE AIR COOLER LEAKAGE TESTING

Two types of leak tests are common:

6.1 Pressure Decay

6.1.1 Procedure

Cap the inlet and outlet of the charge air cooler. One of the caps needs to have an adapter for a supply of compressed air. **THE CAPS NEED TO BE SECURED TO THE CHARGE AIR COOLER WITH CABLES OR CHAINS TO PREVENT BLOW-OFFS**. Attach a shop airline to the adapter with a pressure gauge, regulator and shut-off valve. Supply air to the charge air cooler to the specified maximum pressure, then shut off the valve and measure the time for the pressure in the charge air cooler to decay to the specified minimum pressure.

6.1.2 Criteria

The specified pressures and times are available from the manufacturer of the engine or charge air cooler. Typical values are in the range of a 20-50 kPa (3-7 psi) pressure loss from 100-200 kPa (15-29 psi) gage pressure in 15-60 seconds. The stated values are for reference only as specific requirements will be driven by the engine or CAC manufacturer.

6.2 Submersion Test

6.2.1 Procedure

Supply air per Procedure above while the charge air cooler is submerged in water. Capture the air bubbles that leak from the cooler and measure the volume of leaked air during a specified time period. This procedure is difficult to perform in the field and is primarily used at the charge air cooler manufacturing facility.

6.2.2 Criteria

The specified leak rates at a given pressure are available from the manufacturer of the engine or charge air cooler. Typical leak rates are in the range of 10-200 cc/min (1-12 cubic inches/min) at 100 kPa (15 psi) gage pressure. The stated values are for reference only as specific requirements will be driven by the engine or CAC manufacturer.

7. ADDITIONAL CHARGE AIR COOLER LEAKAGE NOTES

7.1 Leak Rate Trends

In general, allowable charge air cooler leak rates are being reduced by engine manufacturers as newer engines become more sensitive to charge air leakage. The latest engine specifications must be utilized to determine up-to-date requirements.

7.2 Causes of Leaks

Allowable charge air cooler leaks are typically caused by minor defects in welding, brazing or casting processes. These leaks will not get worse over time. Fatigue cracks in a tube, header or tank are not considered allowable leaks and will result in higher leak rates over time as the cracks grow.

8. CHARGE AIR COOLER NOMENCLATURE

For purposes of this SAE Recommended Practice, charge air may be referred to as a fluid when in fact it is a gas. The cooling medium may be referred to as a fluid when in fact either liquids or gases can be employed.

8.1 Hardware

8.1.1 Aftercooler

A charge air heat exchanger located after the compressor (see Intercooler).

8.1.2 Air-to-Air Cooler

A charge air heat exchanger that uses ambient air as the cooling medium. See Figures 6 and 7.

8.1.3 Core

The portion of the heat exchanger that includes the principal heat transfer surface areas. The main core components include the tubes, external fins, internal fins, and oftentimes, the header. Some designs include the header as part of the inlet and outlet tanks. The core components are either brazed or mechanically fastened together. Mechanically fastened core components are connected with expanded joints, sealants or interference fit elastomeric gaskets. These gaskets are sometimes called resilient grommets. Some cores have brazed tube-to-fin joints in combination with elastomeric gaskets between the tubes and headers. Most OEM cores are brazed with one of the following manufacturing processes:

8.1.4 Air Brazing

Brazing the heat transfer components of the core in an air atmosphere and typically employing a corrosive type flux.

8.1.5 Vacuum Braze

Brazing the heat transfer components of the core in a nearly zero atmosphere and typically without the use of liquid flux.

8.1.6 Controlled Atmosphere Braze (C.A.B.)

Brazing the heat transfer components of the core in a controlled atmosphere and typically employing a non-corrosive flux. Typical examples of this brazing process include aluminum alloy brazing by the NOCOLOK® process and copper alloy brazing by the CUPROBRAZE® process, which typically employ a nitrogen atmosphere.

8.1.7 Dip Braze

Brazing the heat transfer components of the core in a molten metal or salt bath.

8.1.8 Exothermic Braze

Brazing the heat transfer components of the core through the employment of an exothermic compound sufficient to reach the brazing temperature of the filler metal.

8.1.9 Torch Braze

The heat transfer components of the core are joined mechanically by expanding the tubes. The tube-to-header joints are torch brazed.

8.1.10 External Fins

Secondary surfaces that increase the area to transfer heat to the cold fluid.

8.1.11 Header

The portion of the core that connects the inlet and outlet tanks to the core matrix. The ferrules are typically formed or pierced.

8.1.12 Inlet Ducts

The portions of the cooling system that direct the fluids into the inlet tanks of the heat exchanger.

8.1.13 Inlet Tanks

The portions of the heat exchanger located between the compressor and the intake manifold or between series compressors that direct the fluids into the core matrix.

8.1.14 Intercooler

A charge air heat exchanger located between the compressor and the intake manifold or between series compressors.

8.1.15 Internal Fins

Secondary surfaces that increase the area that is to transfer heat from the hot fluid.

8.1.16 Air-to-Coolant Cooler

A charge air heat exchanger that uses the engine coolant or other external liquid coolant as the cooling medium. See Figures 2, 3, 4, and 5.

8.1.17 Multipass

A charge air heat exchanger that passes the fluids through the core matrix more than once.

8.1.18 Outlet Ducts

The portions of the cooling system that direct the fluids out of the outlet tanks of the heat exchanger.

8.1.19 Outlet Tank

The portion of the heat exchanger that direct the fluids out of the core matrix.

8.1.20 Remote Mounted

A charge air heat exchanger that is located (mounted) in an area not normally associated with or convenient to the cooling medium.

8.1.21 Single Pass

A charge air heat exchanger that passes the fluids through the core only once.

8.1.22 Tubes

The portions of the heat exchanger core matrix that are used to separate the fluids and are also the primary heat transfer surface areas. (See Figure 1 for typical tube types.)

8.1.23 Turbulator

Secondary surfaces that increase the turbulence and mixing of the cold or hot fluids.

8.2 Operating and Performance Parameters

8.2.1 Ambient Temperature

The temperature of the air surrounding the engine or vehicle before such air is influenced by heat or work energy from the engine or vehicle.

8.2.2 Boost Pressure

The pressure of the charge air as it leaves the turbocharger, supercharger, or other compressor.

8.2.3 Density Recovery Efficiency

The ratio of the charge air density increase achieved from cooling the charged air, to the density decrease due to the temperature rise in the process of compressing the charge air.

8.2.4 Density Recovery Ratio

The ratio of the charge air density at the engine intake manifold to the air density at conditions of ambient temperature and boost pressure.

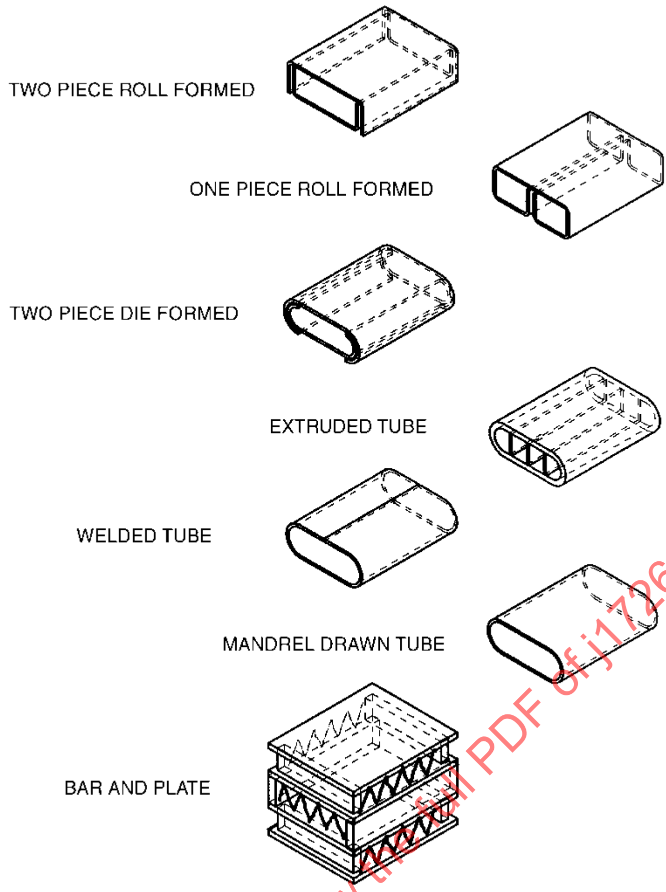


Figure 1 - Charge air cooler tubes

8.2.5 Inlet Pressure

The pressure of the charge air as it enters the heat exchanger.

8.2.6 Inlet Temperature

The temperature of the fluids as they enter the heat exchanger.

8.2.7 Inlet Temperature Differential (ITD)

The inlet temperature difference between the hot and cold fluids.

8.2.8 Intake Manifold Pressure

The charge air pressure in the intake manifold.

8.2.9 Intake Manifold Temperature

The charge air temperature in the intake manifold.

8.2.10 Intake Manifold Temperature Differential (IMTD)

The difference between the charge air temperature in the intake manifold and the ambient temperature.

8.2.11 Mass Flow Rate

The rate of flow of the hot and cold fluids through the heat exchanging system expressed in terms of mass units per unit time.

8.2.12 Operating Conditions

The conditions under which the heat exchanger must operate; usually determined or set as the most severe conditions the heat exchanger will operate under continuously.

8.2.13 Outlet Pressure

The pressure of the fluids as they exit the heat exchanger.

8.2.14 Outlet Temperature

The temperature of the fluids as they exit the heat exchanger.

8.2.15 Pressure Drop

The difference in fluid pressures as measured between the inlet and outlet of the heat exchanger or heat exchanging system.

8.2.16 Temperature Drop

The difference in the fluid temperatures as measured between the inlet and outlet of the heat exchanger or heat exchanging system.

8.2.17 Temperature Effectiveness

The ratio of the inlet charge air temperature minus the outlet charge air temperature divided by the inlet temperature differential.

8.2.18 Test Conditions

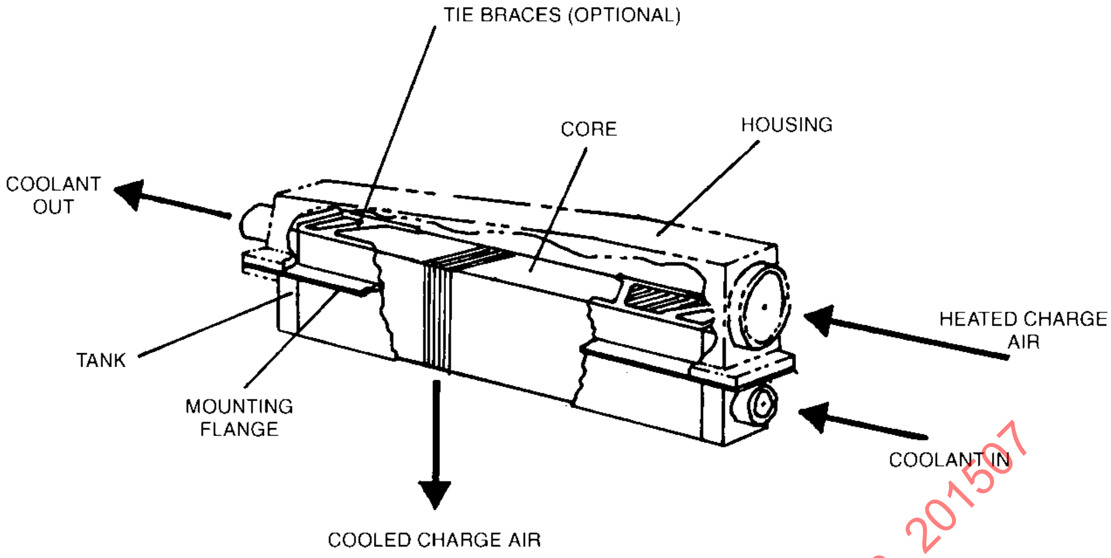
The conditions under which the heat exchanger is tested to determine its effectiveness and pressure drop, usually the same as the operating conditions.

9. SCHEMATICS OF TYPICAL CHARGE AIR COOLERS

9.1 Air-to-Coolant Heat Exchangers

9.1.1 Mounted in the intake manifold (see Figures 2 and 3)

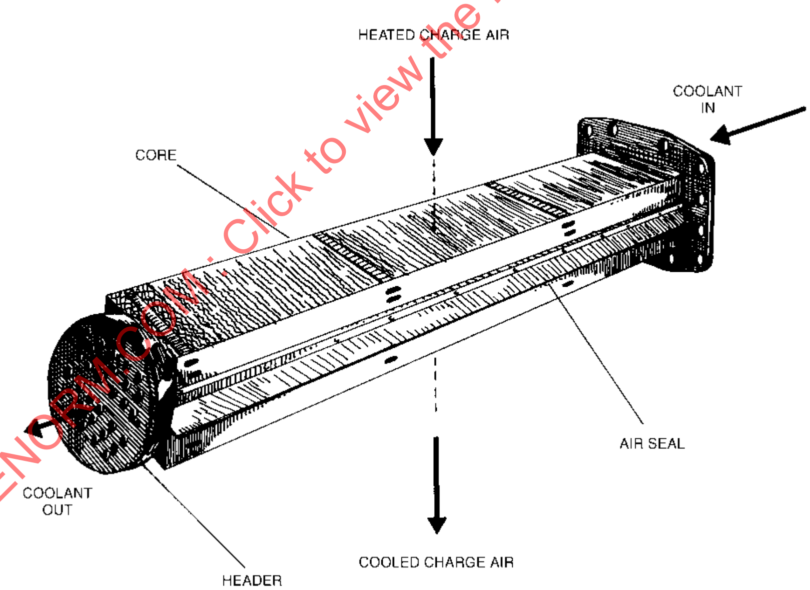
9.1.2 Mounted remotely (see Figures 4 and 5)



NOTE—Coolant sources can be varied.
Materials have to be compatible with the type of coolant and environment.

Coolant traverses may be a single pass or a multipass arrangement.

Figure 2 - Air-to-coolant - mounted in intake manifold



NOTE—Coolant sources can be varied.
Materials have to be compatible with the type of coolant and environment.

Coolant traverses may be a single pass or a multipass arrangement.

Figure 3 - Air-to-coolant - mounted in intake manifold