



SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Charge Air Cooler Internal Cleanliness, Leakage, and Nomenclature

RATIONALE

SAE Five-Year Review.

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 (CAC) 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 reduction in compressed air temperatures increases intake air density, providing more air mass flow and allowing more fuel delivery, with corresponding improvement in engine power output. The cooler charge also enables an optimized combustion process, which improves both emissions and fuel economy performance. Typical cooling media include the engine's coolant, a low temperature coolant circuit, or ambient air.

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

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- 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 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 ASTM Publications

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, Tel: 703-838-1763, <https://tmc.trucking.org/>.

- TMC 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 manufacturer criteria, the following guidelines are recommended:

Chemical cleanliness (see 3.1 to 3.3) typically applies only to natural gas engines.

Debris cleanliness (see 3.4 to 3.7).

- 3.1 Maximum Potassium Level ≤ 60 parts per million (ppm)
- 3.2 Maximum Fluoride Level ≤ 46 ppm
- 3.3 Maximum Aluminum Level ≤ 12 ppm
- 3.4 Maximum Total Weight of Debris = 25.0 mg (8.82×10^{-4} ounces)

This is a recommendation based on a "typical" on-highway CAC with a face area of 0.20 to 1.0 m² 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 inch)

3.6 Maximum Individual Debris Particle Area = 2.58 mm² (0.004 in²)

3.7 Maximum Individual Debris Particle Weight = 1.4 mg (4.94 x 10⁻⁵ ounces)

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 Chemical Cleanliness

4.1.1 Apparatus for Chemical Cleanliness

- Laboratory glassware
- Laboratory supplies
- Ion chromatograph (IC)
- Atomic absorption (AA) spectrophotometer

4.1.2 Procedure for Determining Chemical Cleanliness

- 4.1.2.1 All laboratory glassware used for testing must be clean and triple rinsed with ASTM D1193 Type I reagent water.
- 4.1.2.2 Obtain clean and rinsed rubber stoppers to seal CAC so it is watertight.
- 4.1.2.3 Plug all CAC ports except the one highest in the unit under test.
- 4.1.2.4 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.
- 4.1.2.5 Once the CAC is full of water, seal the last port and let the unit under test sit stationary at room temperature for 8 hours.
- 4.1.2.6 After 8 hours, carefully drain the CAC into a clean vessel that will hold the total internal volume of solution from the CAC.
- 4.1.2.7 Once all the solution is collected from the CAC in the vessel, stir the solution with a stir rod until it is sufficiently mixed.
- 4.1.2.8 With a clean sample bottle, remove approximately 100 mL of solution from the vessel for chemical analysis.
- 4.1.2.9 Using standard laboratory procedures outlined in ASTM documents in section 2.2.1, analyze the solution sample with an AA, or ICP and IC, to determine the flux chemical element levels in parts per million. Compare these results to the criteria provided above. External analytical laboratories can be used as resources dictate.

4.1.3 The chemical cleanliness report should include the following:

- Customer part number
- Manufacturer's part number

- Date of manufacture
- Chemical cleanliness levels

4.2 Debris Cleanliness

4.2.1 Apparatus for Debris Cleanliness

- 5.0 µm qualitative-grade filter paper
- 0.5 µm 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 nonmetallic CAC component parts and assemblies. If possible, CAC 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

4.2.2 Procedure for Determining Debris Cleanliness

- 4.2.2.1 All glassware and the test area used for determining CAC compliance with this document must be clean and free from debris.
- 4.2.2.2 Filter the selected test solvent through a 0.5 µm membrane filter paper. Replace with a new filter paper if total debris causes clogging.
- 4.2.2.3 Place a 5.0 µm qualitative-grade filter paper in the drying oven at 100 °C (212 °F) for 15 minutes. 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} ounces) 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.
- 4.2.2.4 Position the CAC so that the inlet and outlet portals are facing upwards. If ports face in opposite directions, cap one port and face the other 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.
- 4.2.2.5 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 ten 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 one cycle.

- 4.2.2.6 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 µm filter paper, which has been set up in the vacuum filtering assembly.
- 4.2.2.7 The spent filtrate can be used for future CAC testing after it has been filtered through a 0.5 µm filter paper.
- 4.2.2.8 Remove the filter paper from the filtering assembly and place it in the drying oven at 100 °C (212 °F) for 15 minutes. 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 (3.5×10^{-6} ounces) with an analytical balance as Wte.
- 4.2.2.9 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.
- 4.2.2.10 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.

4.2.3 The debris cleanliness 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 CACs are acceptable and describe test methods to measure these leaks. Brazed aluminum, air-to-air CACs have been used since the early 1980s on many turbocharged diesel engines. It is difficult to manufacture CACs 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 CACs.

6. CHARGE AIR COOLER LEAKAGE TESTING

Three types of leak tests are common: pressure decay, submersion, and mass flow.

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 shutoff 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 CAC. Typical values are in the range of a 20 to 50 kPa (3 to 7 psi) pressure loss from 100 to 207 kPa (15 to 30 psi) gauge pressure in 15 to 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 previous procedure 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. 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 CAC. Typical leak rates are in the range of 10 to 200 cm³/min (1 to 12 in³/min) at 100 kPa (15 psi) gauge pressure. The stated values are for reference only, as specific requirements will be driven by the engine or CAC manufacturer.

6.3 Mass Flow Leak Test

6.3.1 Procedure

This type of leak testing typically requires the use of an automated mass flow leak tester that flows a measured amount of air into the heat exchanger and measures the amount of air leaking as a volumetric flow rate, such as cc/min. Connect the automated mass flow leak tester to the CAC port(s). Activate the test cycle. The tester should be programmable and provide a pass/fail signal.

6.3.2 Criteria

See 6.2.2.

6.4 Other leak test methods are being developed and may be able to be used in production and lab environments, such as tracer gas mass spectrometer. These methods are generally used to detect smaller leaks than pressure decay or mass flow leak testing.

7. ADDITIONAL CHARGE AIR COOLER LEAKAGE NOTES

7.1 Leak Rate Trends

In general, allowable CAC 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 CAC 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, or crimp defects at an end tank, are not considered allowable leaks and will result in higher leak rates over time as the crack or crimp defect grows.

8. CHARGE AIR COOLER NOMENCLATURE

For the purposes of this SAE Recommended Practice, charge air and cooling medium will both be referred to as fluids. In this context, fluid may refer to either gas or liquid.

8.1 Components

8.1.1 Core

The core is 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.

8.1.1.1 Air Brazing

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

8.1.1.2 Controlled Atmosphere Braze (CAB)

Brazing the heat transfer components of the core in a controlled atmosphere and typically employing a noncorrosive flux. Typical examples of this brazing process include aluminum alloy brazing by the NOCLOK® process and copper alloy brazing by the CuproBraz® process, which typically employ a nitrogen atmosphere.

8.1.1.3 Dip Braze

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

8.1.1.4 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.

8.1.1.5 Torch Braze

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

8.1.1.6 Vacuum Braze

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

8.1.2 External Fins

Secondary surfaces that increase the area to transfer heat to the cooling media.

8.1.3 Header

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

8.1.4 Inlet Ducts

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

8.1.5 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.

8.1.6 Internal Fins

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

8.1.7 Outlet Ducts

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

8.1.8 Outlet Tank

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

8.1.9 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.)

8.1.10 Turbulator

Secondary surfaces that increase the turbulence and mixing of the cold or hot fluids to improve heat transfer. Internal fins (see 8.1.6) are often referred to as turbulators.

8.2 Configurations

8.2.1 Aftercooler

A charge air heat exchanger located after the compressor (see 8.2.4).

8.2.2 Air-to-Air Cooler

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

8.2.3 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.

8.2.4 Intercooler

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

8.2.5 Multipass

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

8.2.6 Remote Mounted

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

8.2.7 Single Pass

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

8.3 Operating and Performance Parameters

8.3.1 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.

8.3.2 Boost Pressure

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

8.3.3 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.

8.3.4 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.

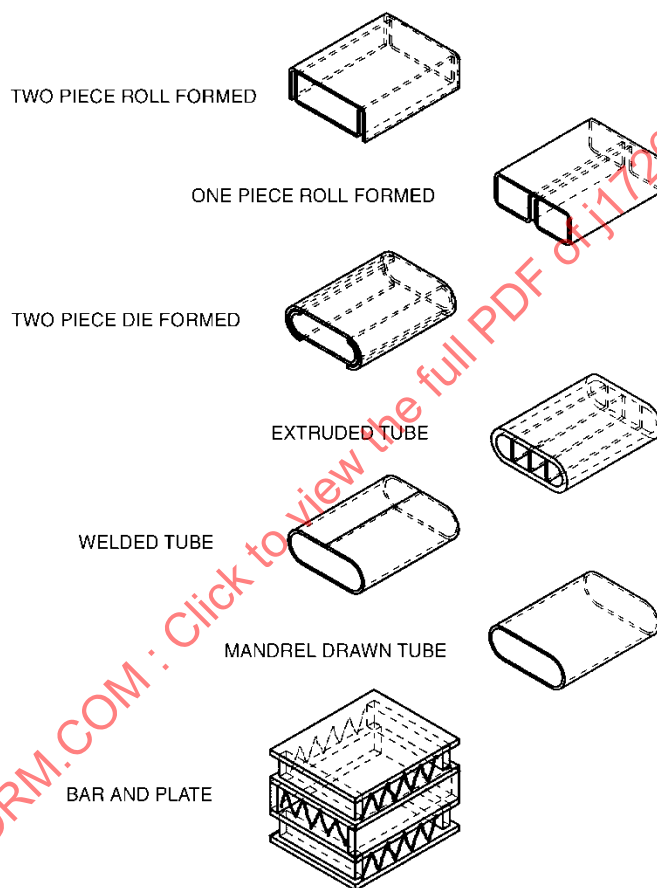


Figure 1 - Charge air cooler tubes

8.3.5 Inlet Pressure

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

8.3.6 Inlet Temperature

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

8.3.7 Inlet Temperature Differential (ITD)

The inlet temperature difference between the hot and cold fluids.

8.3.8 Intake Manifold Pressure

The charge air pressure in the intake manifold.

8.3.9 Intake Manifold Temperature

The charge air temperature in the intake manifold.

8.3.10 Intake Manifold Temperature Differential (IMTD)

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

8.3.11 Mass Flow Rate

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

8.3.12 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.

8.3.13 Outlet Pressure

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

8.3.14 Outlet Temperature

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

8.3.15 Pressure Drop

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

8.3.16 Temperature Drop

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

8.3.17 Temperature Effectiveness

The ratio of the charge air temperature drop (see 8.3.16) divided by the ITD (see 8.3.7), typically expressed as a percentage (less than 100%).

8.3.18 Test Conditions

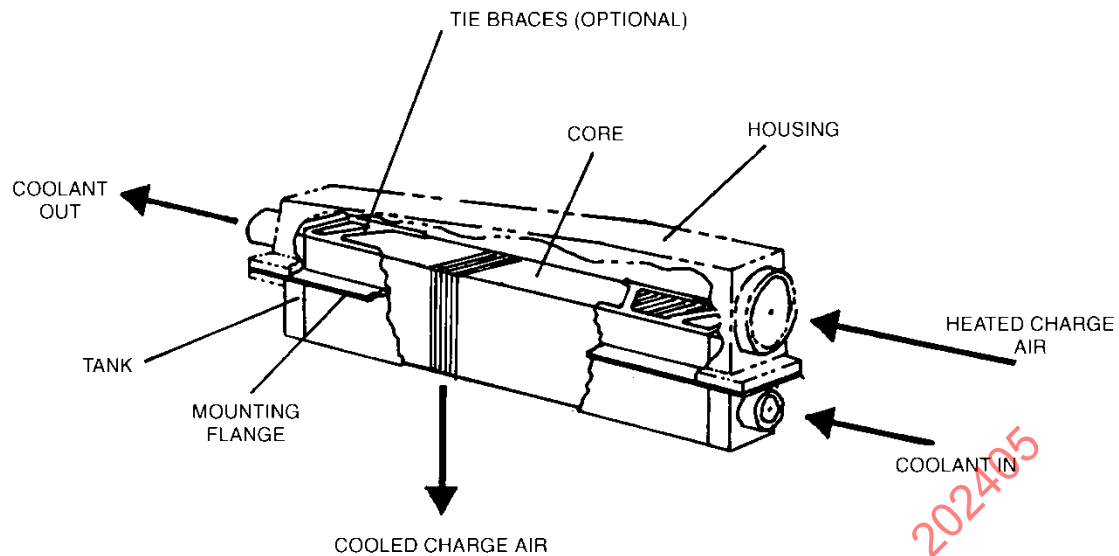
The conditions under which the heat exchanger is tested to determine its effectiveness and pressure drop, usually the same as the operating conditions.

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)

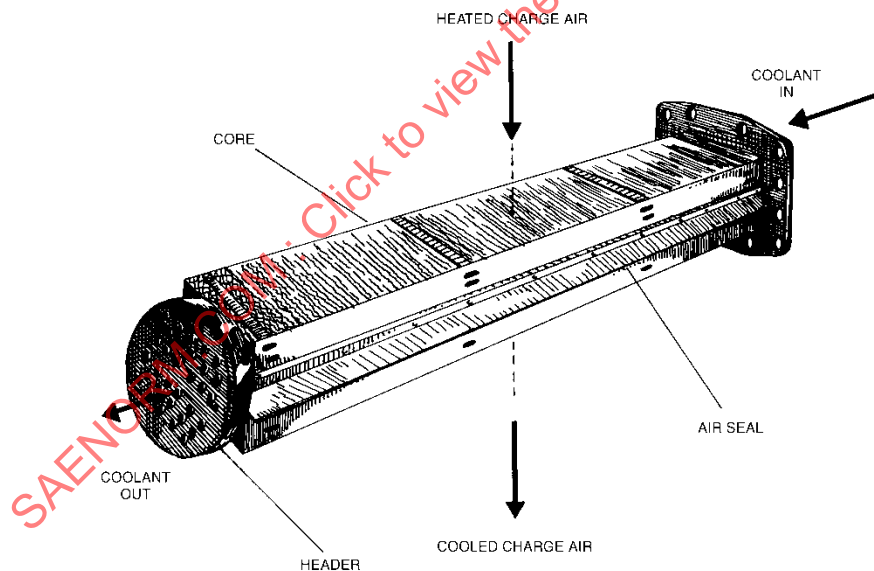


NOTE—Coolant sources can be varied.

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