Engine Division

August 2006

Product News

Air-to-Air Aftercooling System

Market	Industrial
Application	Air-to-Air Aftercooled engines in industrial applications
Description	Updated information on design, evaluation, and testing of Air-to-Air Aftercooling systems
Features/Benefits	System description Design System evaluation Test procedure

Introduction

The function of an Air-to-Air Aftercooled engine cooling system arrangement is to improve fuel consumption and to lower emissions to meet government regulations, and in some cases to permit increased horsepower. The success of this cooling system arrangement is dependent on the reduction of engine intake air manifold temperature.

Cooling System Description

The heated charge air from the engine turbocharger is ducted to an engine mounted Charge Air Cooler (CAC), which is positioned in series or parallel with the conventional engine radiator (figure 1). The engine fan moves cooling air through the CAC and reduces the charge air temperature. The air is then ducted to the engine intake manifold. Peculiar to the uniqueness of each engine design, customers should note the following design guidelines as applied to these components:

- Charge Air Cooler (CAC)
- CAC & radiator packaging
- Ducting
- Turbocharger air outlet
- Safety controls
- Connections
- Clamps and restraints

Design

Charge Air Cooler (CAC)

Pressure drop from the compressor outlet to the inlet manifold at rated speed and load should not exceed 4 in Hg (13.6 kPa) or as specified in the Engine Performance Data. Each unit should be inspected after manufacture to ensure minimal charge air leakage.

CAC and Radiator Packaging

The CAC and radiator cores can be packaged in parallel or in series (figure 1). The parallel configuration is advantageous for applications with severe clogging because it provides a single surface for air flow path. The series configuration has multiple surfaces air flow path and some debris may go through the first core, then drop as the air velocity falls, thereby clogging the second core. Another advantage of the parallel configuration is packaging simplicity. Unlike the series configuration, the parallel configuration will work with either a blower or a suction fan without relocation of the CAC. Also, parallel configuration provides an easy setup for conducting the air venting cooling test. Environments with dust, dirt, and debris will clog heat exchanger cores and degrade cooling efficiency. It is recommended that for severe clogging applications the fin spacing does not exceed seven fins/inch and the fin design be non-louvered with in-line tube pattern. For other industrial applications, a nine fin/inch maximum spacing and non-louvered fin design is recommended. Baffling should be provided around the CAC and the radiator cores to prevent air recirculation.

Ducting

The ducting must be made of aluminized steel or aluminum material and can be 3 in. (76 mm) to 4.5 in. (114 mm) in diameter. The smaller size can be considered if the total system does not exceed the charge air pressure drop limitations. Care must be taken to design ducting supports as necessary to prevent vibration and premature connection fatigue.

Connections

Ducting connections must be designed for high reliability and durability, and because of the relative movement between the engine and CAC there is a need to provide flexibility in the ducting connection. Usually, heat resistant silicon hump type hoses are capable of supplying the needed flexibility for long life applications.

Refer to Engine Data Sheets for operating temperature and pressure. It is recommended that the hoses be suitable for operation at -40°F (-40°C) and capable of a proof pressure of 40 psi (277 kPa) at 350°F (177°C) and a minimum burst pressure of 100 psi (689 kPa) at 600°F (316°C). Hoses should also be capable of withstanding a negative pressure of 20 in. H2O (5 kPa) to prevent collapse. In addition, the hose design must have the capability to withstand flow pressure pulsations and the relative motion of the connecting pipes. These hoses must have the integrity not to distort during engine operation. Care must be taken to ensure that all connections remain tight to prevent loss of air boost pressure which would cause a loss of power and an increase in fuel consumption, and dirt entry which could cause premature engine wear-out.

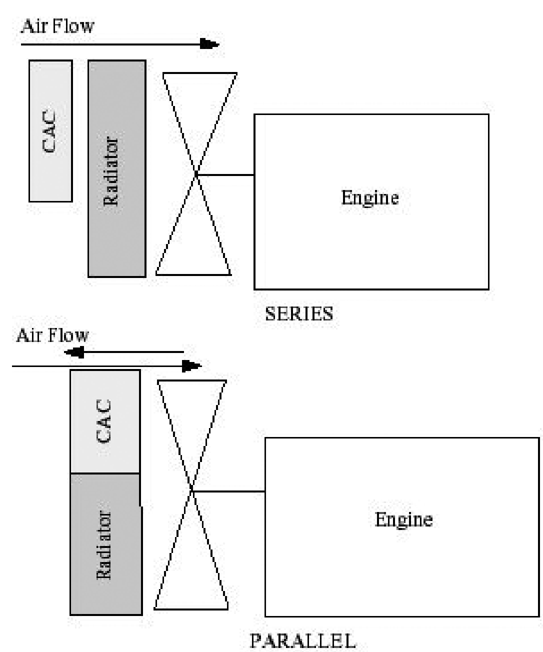


Figure 1: Cooling System Configurations

Turbocharger Air Outlet

A selection of turbocharger outlet elbows are available from Caterpillar for adapting to any ATAAC engine installations. Any new elbow design must be analyzed and approved by Caterpillar to determine that the forces imposed on the turbocharger are acceptable. Pressure tap P1 must be located as illustrated in Figure 2 and at a right angle to the bend of the elbow. Some engine arrangements have a hose type connection directly on the turbocharger compressor outlet.

Clamps and Restraints

Depending on the connections selected, the clamping devices must be capable of a high integrity seal for long life applications, and for preventing ducting separation. It is recommended that a double clamping of hump connecting hoses be coupled with the beaded ends on duct tubing. Clamps should be of the constant torque (spring) type to maintain a seal even with creep of hose connection material over time. Mechanical devices may need to be devised if the charge air system geometry is not satisfactory to prevent duct separation.

Safety Controls

Air inlet temperature sensor is required on all ATAAC engines. Plugging of the CAC core and the radiator core (series configuration) can result in high inlet air temperatures which could be detrimental to engine performance and life. The inlet air temperature sensor monitors the intake manifold temperature and warns the operator when air temperature exceeds 75°C for ADEM III engines or as specified in the Electronic Installation Guide.

Air-to-Air Aftercooling System Evaluation

General

The performance of the total Air-to-Air Aftercooling system must be tested to confirm that the specifications for the particular engine and rating are satisfied. Air-to-Air system specifications are shown in the Engine Performance Data. The procurement of data to evaluate the Air-to-Air Aftercooling system can be obtained in conjunction with testing to establish the ambient capability of the radiator cooling system. The following additional instrumentation will be required to evaluate the Air-to-Air Aftercooling system.

Instrumentation Required

Pressure Gauges

Pressure gauges or a manometer are needed to measure the pressure drop across those Air-to-Air Aftercooling system components supplied by the customer. Tapped holes (P1 and P2) for the measurement of the pressure drop are provided in the engine's turbocharger compressor outlet elbow when provided, and the engine intake manifold as illustrated in Figure 2. Proper locations for pressure taps are identified on general dimension drawings.

Temperature Measurement (See Figure 2)

- T1 Ambient temperature thermocouple.
- T2 An averaging grid of thermocouples for the measurement of cooling air temperature into the CAC.
- T3 Temperature of combustion air to engine turbocharger compressor.
- T4 Temperature of combustion air from the turbocharger compressor. The tap that is provided for the measurement of the compressor pressure (P1) can be jointly used for this temperature measurement with the use of a tee. However, the temperature probe must be long enough to be in the air stream.
- T5 Temperature of combustion air in the engine intake manifold. The tap that is provided for the measurement of the inlet manifold pressure (P2) can be jointly used for this temperature measurement with the use of a tee.

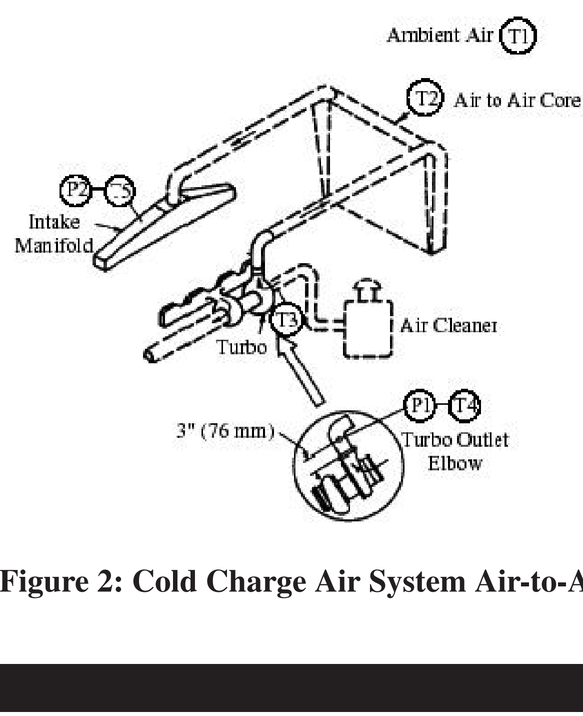


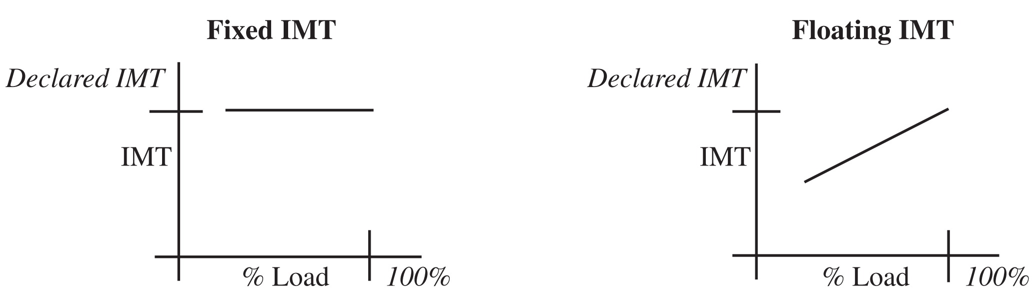
Figure 2: Cold Charge Air System Air-to-Air

Test Procedure

As stated previously, the Air-to Air Aftercooling system can be evaluated in conjunction with testing to establish the ambient capability of the jacket water cooling system. The Air-to-Air Aftercooling test results should be corrected to the ambient temperature specified at the time of certification, usually 77°F (25°C). The test procedure may vary depending on the Inlet Manifold Temperature (IMT) strategy used at the time of emissions certification and, to some extent, the application-specific fan speed strategies. In order to select a test procedure which satisfies certification, an understanding of certification testing and the two inlet manifold temperature strategies is essential. The two strategies are called Fixed (or Known) IMT and Floating IMT.

Floating IMT — This is the strategy typically used for most industrial engines. This strategy is intended to be used with a fan driven off the crankshaft at a constant speed ratio. The emissions certification testing comprises an eight-mode cycle where each mode consists of a specified steady state speed and load condition. One of these speed/load combinations is full load and rated speed, while the other modes are combinations of rated speed and percentage loads, an intermediate speed and percentage loads, and an idle condition. Engines certified to EPA Tier 4 will require some additional emissions test points. During a Floating IMT test, the IMT is set at the declared IMT using the test lab cooling equipment at full load and rated speed. The remainder of the test is carried out with this cooling setting and this, in effect, allows the IMT at other modes to float down i.e. the IMT runs progressively cooler during the other 7 modes of the test.

Fixed IMT — The emissions certification testing comprises an eight-mode cycle where each mode consists of a specified steady state speed and load condition. One of these speed/load combinations is full load and rated speed, while the other modes are combinations of rated speed and percentage loads, an intermediate speed and percentage loads, and an idle condition. Engines certified to EPA Tier 4 will require some additional emissions test points. During a Fixed IMT test the IMT at each of these modes is held at the Declared IMT (Declared IMT = TMI System Data: MAX ALLOW INTAKE MANIFOLD TEMP) by adjusting the test lab cooling equipment.

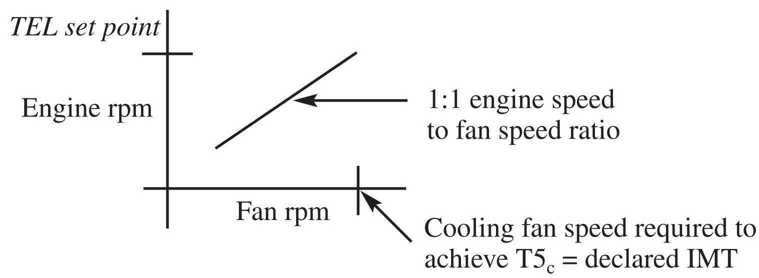


Constant Engine Speed for both graphs

Application Testing, Floating IMT — Testing applications which include an engine certified using the Floating IMT strategy can only be done by ensuring that the corrected IMT does not exceed the declared IMT at full load rated speed. Care must be taken to ensure that the rated speed is not exceeded during this test, since the reduction in fueling after the rated speed point can significantly impact IMT. Also, a cooling fan which runs at a ratio fixed to engine speed is essential for these applications. These fans are usually belt driven off the crankshaft pulley, but they may also be driven by other means, e.g., hydraulically. Such alternatively driven fans must maintain a constant fixed relationship with engine speed, and cannot be varied in the way in which a Fixed IMT would allow. In other words, once the fan speed which gives adequate cooling has been established at rated speed and load, its minimum speed at other engine speeds must remain directly proportional to engine speed, e.g., for a 50 percent reduction in engine speed, the fan speed may not be reduced by more than 50 percent.

Application Testing, Fixed IMT — When testing applications which include an engine certified using the Fixed IMT strategy, it is necessary to ensure that the corrected IMT does not exceed the declared IMT at any speed and load condition. Developing a suitable test procedure will depend upon such things as heat rejection characteristics and the air flow across the charge cooler. One of the advantages of Fixed IMT is that it allows cooling fan speed to be varied with regard to engine load. This reduction in fan speed is desired to reduce noise. For further information on application testing for fixed IMT engines, please contact the Caterpillar Application Support Center.

Engine rpm and Fan Speed for Floating IMT Engines



Key Points

(1) Most industrial engines are certified using a Floating IMT strategy.

(2) Test procedures for engines certified to a Fixed IMT must be designed to ensure that the corrected IMT does not exceed the declared IMT at any condition in the engine load and speed range.

(3) Variable speed fans, not directly linked to engine speed, may be used with Fixed IMT engines if the installed corrected IMT does not exceed the declared IMT at any condition in the engine load and speed range.

(4) The only acceptable test condition for engines certified to a Floating IMT is to run the engine at full load and rated speed. Care must be taken to ensure that the rated speed is not exceeded during this test, since the reduction in fueling after the rated speed point can significantly impact IMT.

(5) Fan speeds used for Floating IMT engines must be sufficient to meet the IMT requirement at full load rated speed, and the fan speed may vary at other engine speeds only at, or better than, the ratio (fan drive to crankshaft) at rated speed, e.g., with the ratio of the fan drive at rated speed equal to 1.1:1, then the ratio at any other speed must be 1.1:1 or greater.

Charge Air System Pressure Drop

Record pressure measurements at the two locations indicated in Figure 2. On the 3406C, 3406E and 3306C engines it is not possible to get a true static pressure measurement at the turbocharger outlet P1 due to the turbulence of the air at this point. Test data indicates that 0.3 in. Hg should be subtracted from the pressure measurement taken at point P1 to make this a true reading on these engines only. The corrected pressure measurement at point P1 (measurement pressure -0.3 in. Hg) minus the pressure measured in the engine intake manifold point P2 is the total pressure drop of the charge air system. This pressure drop must not exceed the value given in TMI System Data: "ALLOW PRESS DROP-COMPR OUT TO MANF IN" for the specified horsepower rating.

Ambient Temperature Measurement

Temperature measurements should be recorded at the locations indicated in Figure 2. The ambient air temperature (T1) is one of the most important value recorded during the cooling system evaluation. As a guideline for the measurement of the ambient air temperature, it is recommended that a thermocouple be placed 3 to 5 ft (.9 to 1.5m) directly ahead and mid-center of the engine. Engineering judgment, particular to each test environment, may require modifications to these guidelines.

Data Processing

If the test ambient (T1) is not at the prescribed 77°F (25°C) or turbo air outlet temperature (T4) does not agree with that stated in the Engine Performance Data the following formulas should be applied to the data.

$$e = \frac{T4 - T5}{T4 - T2} \quad \text{(Aftercooler effectiveness)}$$

$T4_c$ = T4 (spec.) + T3 – T1 (See Note A)

$T2_c$ = 77 + (T2 – T1) (See Note B)

$T5_c$ = $T4_c - e(T4_c - T2_c)$ (See Note C)

c indicates corrected value.

Note A

T4 (spec) is the value stated for the turbocharger air outlet temperature found in TMI System Data: "TURBO COMPR OUT TEMP AT RATED SPEED."

Note B

This equation corrects fan recirculation and/or heat exchanger cores located in front of the Air-to-Air core.

Note C

$T5_c$ is the corrected intake manifold temperature expected when the ambient (T1) is at required 77°F (25°C). The corrected intake manifold temperature ($T5_c$) of an acceptable Air-to-Air system must not be greater than that shown in the TMI System Data: "MAX ALLOW INTAKE MANIFOLD TEMP" for the specified horsepower rating.

Note D

The maximum recommended temperature rise from ambient (T1) to the turbocharger inlet (T3) is 20°F (11°C).