



SURFACE VEHICLE INFORMATION REPORT

J2914™

NOV2022

Issued 2011-11
Revised 2022-11

Superseding J2914 AUG2016

Exhaust Gas Recirculation (EGR) Cooler Nomenclature and Application

RATIONALE

Five-Year Review.

1. SCOPE

This document provides an overview on how and why EGR coolers are utilized, defines commonly used nomenclature, discusses design issues and trade-offs, and identifies common failure modes. The reintroduction of selectively cooled exhaust gas into the combustion chamber is just one component of the emission control strategy for internal combustion (IC) engines, both diesel and gasoline, and is useful in reducing exhaust port emission of nitrogen oxides (NOx). Other means of reducing NOx exhaust port emissions are briefly mentioned, but beyond the scope of this document.

2. REFERENCES

2.1 Related Publications

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

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 J922 Turbocharger Nomenclature and Terminology

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

SAE J1994 Laboratory Testing of Vehicle and Industrial Heat Exchangers for Heat Transfer and Pressure Drop Performance

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2022 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
<http://www.sae.org>

SAE WEB ADDRESS:

Full document details: [SAE J2914_202211](http://www.sae.org/standards/content/J2914_202211)

For more information on this standard, visit
https://www.sae.org/standards/content/J2914_202211/

Documents

Document Sharing Hub

3. SYSTEM ARCHITECTURES FOR EXHAUST GAS RECIRCULATION (EGR) COOLER APPLICATION

3.1 EGR in Internal Combustion Engines

EGR is a combustion strategy of scavenging some of the exhaust gas, cooling it, and then mixing it with fresh charge air, before entering the cylinder to achieve a target inlet manifold air temperature (IMT). The two effects are an increase in specific heat of the charge air mixture entering the cylinder, and a decrease in maximum flame temperature due to lower oxygen content. For a given fuel energy released by the burned fuel, the peak combustion gas temperature in the cylinder is reduced with the desired effect of reducing NO_x output. The higher the percentage mass of EGR, the lower the peak combustion gas temperature, and the lower the NO_x produced. Since the heat removed from the EGR flow is transferred into the engine coolant, the downside is a corresponding increase in jacket water (JW) heat rejection and required external cooling system capacity.

3.1.1 Implications on Engine Design

The addition of EGR into combustion intake flow requires a larger pressure differential across the cylinder to force that mass flow. This differential is not significant in engine air system design in IC engines at lower power density or brake mean effective pressure (BMEP). But for higher BMEP ratings, especially heavy duty (HD) diesels with turbochargers, higher pressure ratio turbo charging is required than without EGR flow. Increased EGR heat rejection often requires an increase in JW pump capacity to maintain the same desired ΔT across the radiator at design point heat load.

All the following applications of EGR coolers are illustrated with turbocharged EGR air system architectures, and are shown with air to air coolers (CACs) in the external cooling system. Only the charge air cooling (CAC) related system components are shown. For simplified illustration, other heat exchangers in the coolant circuits (JW or low temperature circuits) are not shown, nor are components of the external cooling system (fans, radiators, etc.).

3.2 EGR System Architecture Types

3.2.1 Low Pressure Loop EGR

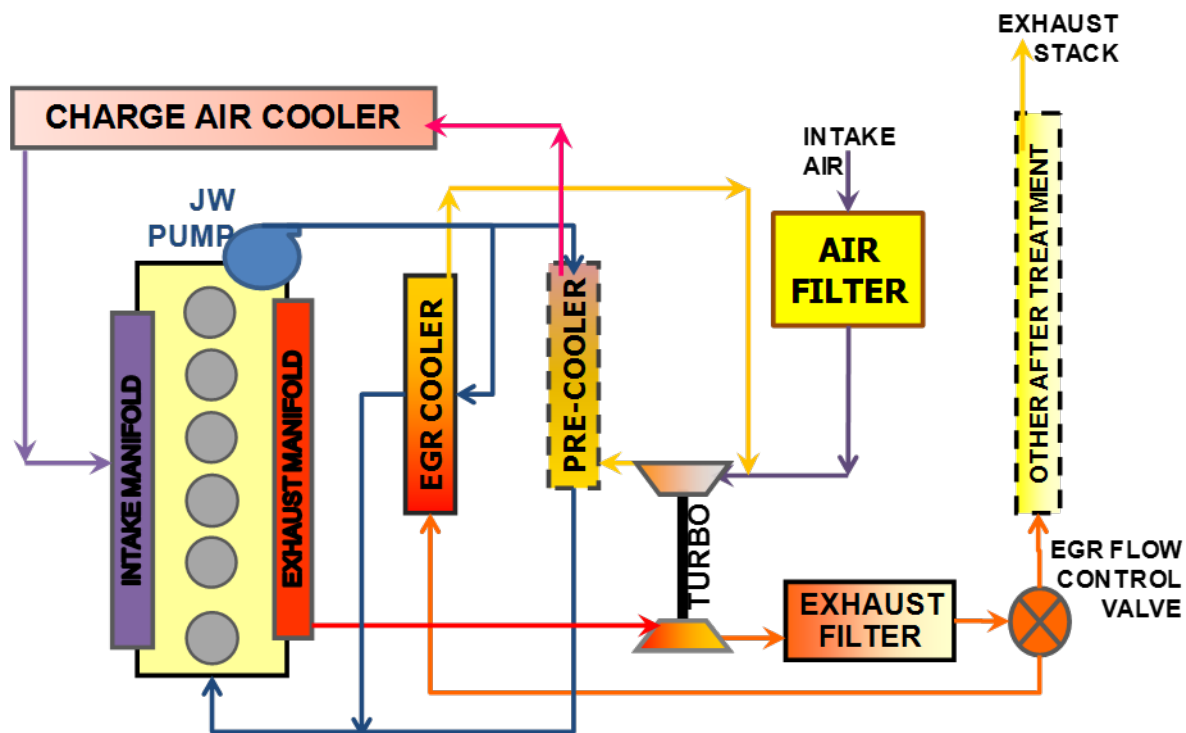


Figure 1 - Low pressure loop EGR schematic

Low pressure loop (LPL) EGR is differentiated by its source of exhaust gas taken from the downstream low pressure side of the turbocharger. Less thermal energy removal (cooling system heat load) is required to reach the desired IMT, since the exhaust gas has already lost some energy after exiting the turbine. Although not required, the gas may also be drawn downstream of the exhaust particulate filter (as shown in Figure 1), resulting in less particulate matter entering the cylinder before combustion. Both have the added benefit of even lower temperature exhaust to be cooled. The pre-cooler shown in both the LPL and high pressure loop (HPL) figures is optional, and only used if high enough pressure ratio turbo charging requires cooling of the charge air ahead of the CAC to stay below material temperature fatigue limits of the CAC core.

Advantages of low pressure loop EGR architecture:

1. The biggest advantage of LPL EGR after the exhaust filter (particulate matter (PM) trap), is that cleaned exhaust is reintroduced to the cylinder for combustion, with reduced vulnerability to piston, ring, and liner wear related to abrasive exhaust particles.
2. The risk of abrasive wear on the thin walled tubes of the EGR cooler and fouling of the wall surface are also reduced. If the exhaust gas is taken upstream of the PM trap then these two advantages disappear.
3. Because the exhaust gas enters the EGR cooler at a temperature lower than the following high pressure loop (HPL) configuration, the risk of boiling failure modes is decreased. Sufficient JW flow entering the cooler is still required to prevent boiling on the tubes and tube-header joints at the inlet, but to a lesser degree. Thermal cycle fatigue is still a major issue, and not considered a major reduction in risk with LPL architecture.
4. Turbo charger speed and efficiency is less affected by EGR rate than the HPL configuration.
5. Mixing of fresh air and EGR flow is very complete.

Disadvantages of low pressure loop EGR architecture:

1. A major disadvantage of the LPL configuration is that corrosive exhaust gas is exposed to various components downstream of the EGR cooler, e.g., mixer valve, compressor, and CAC. This creates more expensive material choices and/or coatings to prevent corrosion.
2. The higher humidity levels of the mixed gases (exhaust and fresh air) entering the CAC will create condensation. Under loaded conditions this frequently results in a corrosive liquid entering the cylinders which can have various detrimental effects. Under extended no load (idle) conditions, condensation can collect in the CAC since air velocities are not high enough to purge it. This can create a slugging (hydraulic lock) risk when the engine speed is subsequently increased.
3. Since the exhaust temperature enters the EGR cooler at a lower temperature than the HPL system, the EGR heat transfer surface area required is increased due to the lower entering temperature difference, all other variables being equal. This results in either very closely spaced tubes (adding coolant side restriction and the risk of localized boiling), or larger space required for the core matrix.
4. The addition of exhaust piping to feed the EGR cooler from a point downstream of the after treatment adds additional cost and space claim. Furthermore, the integrity of this piping must be maintained over the life of the vehicle since this is an emission related system. In some systems, the operating points may create a vacuum in this line which can draw contaminants into the combustion air system if a leak occurs. Furthermore, the additional piping may increase engine or vehicle enclosure temperatures depending on the configuration design.

3.2.2 High Pressure Loop EGR

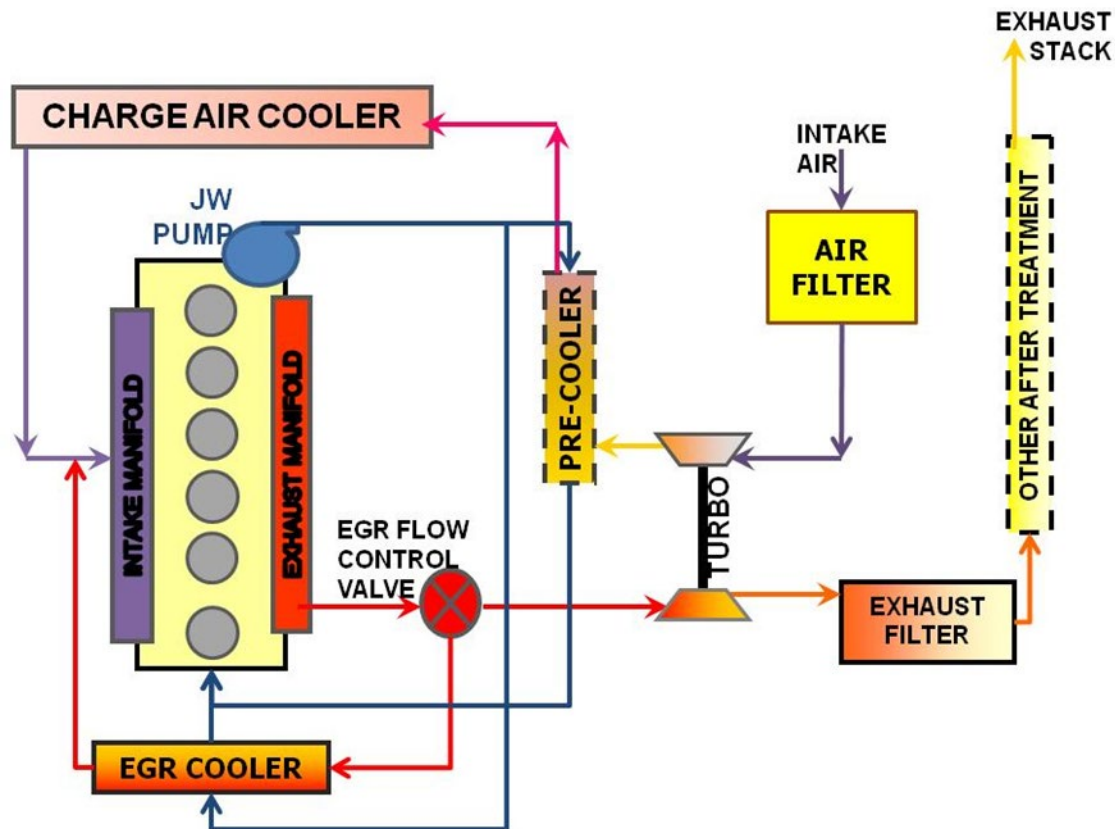


Figure 2 - High pressure loop ERG schematic

High pressure loop (HPL) EGR is differentiated by its source of exhaust gas taken from the exhaust manifold ahead of the turbocharger. More thermal energy removal is required to reach the desired IMT than LPL architecture which extracts exhaust gas further downstream at a cooler temperature. The cooled gas also contains all corrosive and abrasive particles before any after treatment is applied. The pre-cooler is again optional, depending on the charge air temperature from the compressor and the temperature limitations of the CAC material.

Advantages of high pressure loop EGR architecture:

1. The exhaust piping is simpler, with fewer connections, and associated reliability.
2. Since the exhaust temperature source is at its higher temperature, the heat transfer surface area is reduced to meet the cooler effectiveness requirement, everything else affecting EGR cooler size being equal.

Disadvantages of high pressure loop EGR architecture:

1. Because the exhaust gas enters the EGR cooler at higher temperature, the risk of boiling failure modes is increased. More JW flow is required to prevent boiling on the tubes and tube-header joint at the inlet. This drives increased flow-capacity required from the JW pump.
2. Thermal cycle fatigue within the EGR core matrix is also a greater risk with the higher differential between hot and cold fluid temperatures.
3. Because the exhaust gas contains abrasive particulate matter, risk of abrasive wear is increased inside the core matrix in areas of high velocity, which may drive material selection of the thin walled EGR cooler tubes or plates.

4. The presence of unfiltered particles in the cylinder intake stream occurs as the exhaust flow enters the cylinder, increasing piston, ring, and liner wear.
5. Fouling of the exhaust side passages will occur to a greater degree than the LPL filtered circuit. Fouling factor, or degradation from new, must be factored in to the design related to heat transfer performance as well as gas side pressure drop. Provisions for cleaning a fouled cooler are also a serviceability issue.

3.2.3 Two-Stage EGR Coolant Circuits

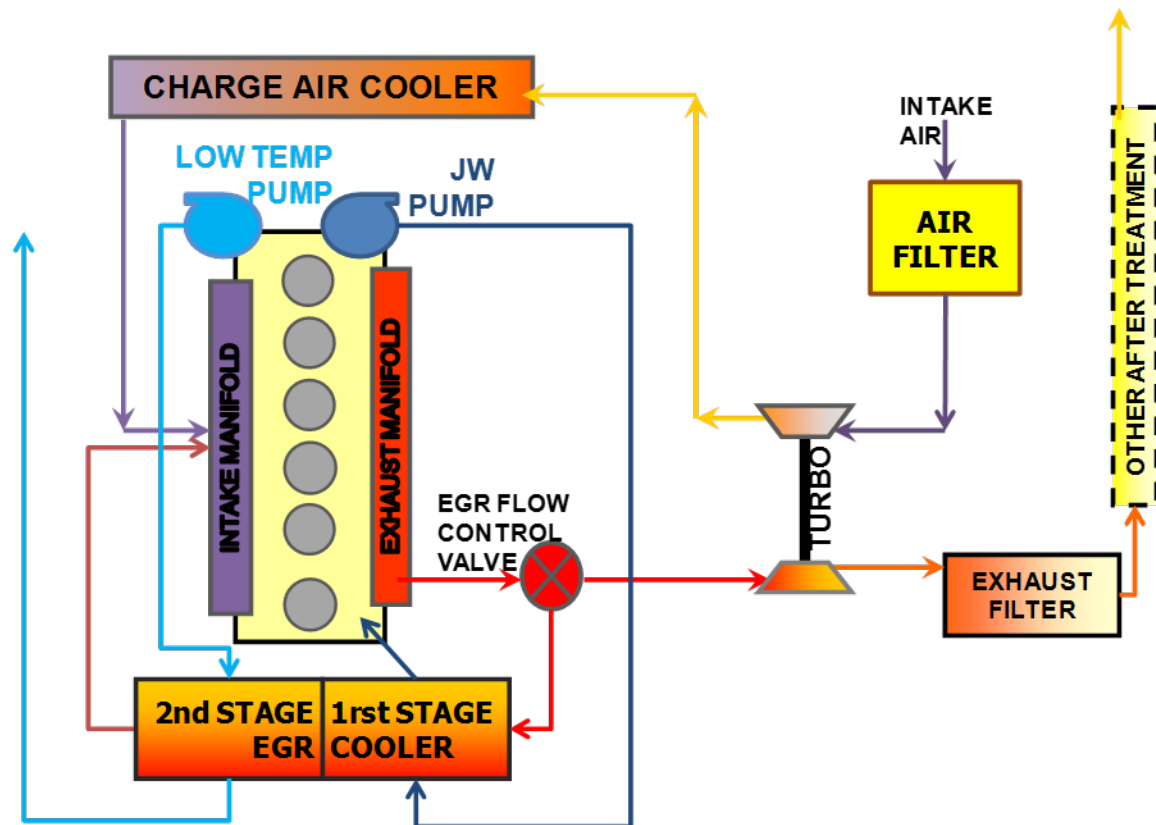


Figure 3 - Two-stage EGR schematic

This third variation illustrates a difference in the coolant side of the EGR architecture. It is applicable to both LPL and HPL configurations, and is independent of the presence of a charge air pre-cooler upstream of the CAC. The differentiating feature is that the EGR cooler is a single pass gas side design, but with two separate coolant circuits passing through the liquid side. The first stage cools the gas in the JW circuit, as in earlier diagrams. But a second, lower temperature coolant circuit, with temperature available below JW thermostat controlled temperature, is used to further lower the exhaust gas temperature, thereby increasing its density and decreasing exhaust port NOx.

Advantages of two-stage EGR cooling architecture:

1. The lower temperature of the exhaust at the intake manifold lowers the mixed IMT, and the increased density increases the ratio of EGR flow. Both reduce the NOx content at the exhaust port and reduce the need for further downstream after-treatment.
2. If the IMT goal is equal to the single stage configuration, the lower temperature coolant in the second stage increases the overall entering temperature difference ΔT available to the cooler, allowing less surface area and space required for a given heat load removal.

1. If the overall cooling system already includes a low temperature circuit with other auxiliary coolers, then there is a small penalty for increased flow capacity for the addition of the EGR cooler second stage. But if the EGR cooler is the only heat exchanger in the low temperature circuit, then the penalties for the addition of a second coolant pump, low temperature radiator, and associated water lines add cost, space requirements, weight, and reliability risk.
2. The design of the cooler itself is structurally more challenging since thermal gradients between high and low temperature sections of the cooler are higher than a single stage cooler.

3.2.4 Donor Cylinder EGR



Now is directed to the EGR cooperation systems.