

EGR System Fouling Control

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ABSTRACT

Exhaust gas recirculation (EGR) is effective in reducing engine-out NO_x emissions; however, the EGR system is subject to fouling and corrosion. Fouling is mainly due to particulate buildup on the EGR component (e.g., EGR valve and cooler) surfaces. Corrosion is primarily related to oxides of sulfur and nitrogen in the gas stream, especially problematic when condensation occurs [1]. Because cooled EGR is most effective in controlling NO_x emissions, EGR cooler design and operation are important considerations in engine design in order to meet durability requirements. An approach has been developed to greatly reduce EGR system fouling. Four EGR coolers were tested simultaneously with various PM control devices installed upstream of the cooler. System configuration and on-engine test results are presented herein.

INTRODUCTION

Environmental regulations for diesel engine emissions are becoming increasingly stringent, and are driving efforts to develop concepts to reduce emission levels, predominantly for particulate matter (PM) and oxides of nitrogen (NO_x). The use of cooled exhaust gas recirculation (EGR) is considered to be an effective approach to reduce NO_x emissions in order to meet US2010 emissions regulations.

EGR creates a challenging environment for the engine to handle different gas compositions and temperature. Therefore, EGR introduces material durability and design issues, such as [2]:

- Material selection/optimization of the EGR components to optimize heat transfer efficiency and resist corrosion and fouling of EGR coolers.
- Controls of the EGR system, including the EGR throttle and diverter valves.
- Overall EGR system packaging to withstand heavy vibration and the engine environment.

For high pressure EGR cooler loops, EGR cooler fouling tends to be one of the predominate factors for EGR system failures in the field. Although fouling may not cause a catastrophic failure, it will significantly reduce heat transfer efficiency in the cooler over time. This

failure mode will lead to higher EGR gas temperatures, causing engine-out NO_x to increase.

In diesel applications, there have been two main factors that are attributed to EGR cooler fouling [3]:

- Specific particle size deposition – this factor depends on particle size and on the EGR cooler internal tube design. Some suppliers use fins inside the tubes to increase heat transfer efficiency, which may or may not be more susceptible to fouling.
- Thermophoretic deposition – occurs as a result of the temperature gradient between the exhaust gas temperature and the internal surface temperature of the EGR cooler. This deposition mechanism typically depends on the total heat transfer of the exhaust gas through the cooler. As more heat transfer or cooling of the gas phase occurs, more particle deposition is expected to take place.

There are four conditions promote the fouling of an EGR cooler [3]:

- High PM number (or mass) concentration at the inlet of the cooler.
- High gas temperature gradient across the cooler.
- Low gas outlet temperature that promotes condensation inside the cooler.
- Wet particle composition (high soluble organic fraction, or SOF, in PM).

Engine manufactures have been successful in developing better engine control strategies, but these conditions still exist in everyday driving conditions. To prolong the life of the EGR system and maintain a high EGR cooler heat transfer efficiency over the entire service life of the vehicle, PM control devices may be implemented. But, these PM control devices must not inhibit EGR flow or require any regular maintenance during the service lifetime of the vehicle [4]. Although wall flow diesel particulate filters (WF-DPF) can attain high solid PM filtration efficiencies (>95%), active DPF regenerations in the EGR system may be challenging. A catastrophic failure of a ceramic based substrate DPF could send loose material into the intake, potentially damaging the turbocharger or other intake components.

Hence, a metallic partial flow DPF (PF-DPF) substrate would be a viable solution because of its robust design.

Presented herein are the results from an EGR cooler fouling study where different PM control devices were implemented upstream of the EGR cooler. Four identical EGR coolers with various PM control devices were simultaneously tested on a 7.3L V8 diesel engine bench. This study addresses both ceramic WF-DPF and metallic PF-DPF substrates and how various catalyst loadings in the metallic substrates impacts EGR cooler fouling.

TEST FACILITIES

TEST ENGINE

A MY 2003 International 7.3L turbocharged diesel engine was used for this program. The 7.3L engine specifications are presented in Table 1.

TABLE 1. TEST ENGINE DESCRIPTION

Engine Type	MY2003
Displacement, cm ³	7300
Maximum Power, HP @ rpm	235 @ 2700
Maximum Torque, N-m @ rpm	678 @ 1600
Bore x Stoke, mm	104 x 162
Compression Ratio	17.5:1
Number of cylinders	8

FUEL AND ENGINE LUBE SPECIFICATIONS

Commercial ultra-low sulfur diesel (ULSD) fuel was used throughout the engine bench testing. The fuel specifications can be found in Table 2.

TABLE 2. TEST FUEL PROPERTIES

Parameters	Units	Value
Aromatics	Vol. %	21.6
Specific gravity	kg/L	0.845
Sulfur content	ppm	11
Cetane number	-	43.0
Flash Point	deg C	77
Net Heating Value	kJ/kg	42,848

Shell Rimula Premium 15W-40 grade oil was used for this program. The oil met API CI-4 Plus, CH-4, CG-4, CF-4, CF and API SL performance specifications.

EXPERIMENTAL APPARATUS

An experimental apparatus was set up at SwRI to accommodate the simultaneous testing of four EGR coolers. A custom exhaust manifold, attached to the exhaust outlet side of the turbocharger, was designed and constructed in such a way as to allow an equal and

controlled split of the total exhaust flow to be fed through four test EGR coolers installed in parallel. Each leg had a different PM control aftertreatment system installed upstream of the cooler. The gas flow rate for each leg was balanced using a SwRI-developed exhaust flow distribution device. A schematic of the test cell setup is given in Figure 1 and a photograph of the fabricated four leg EGR cooler test bench is shown in Figure 2.

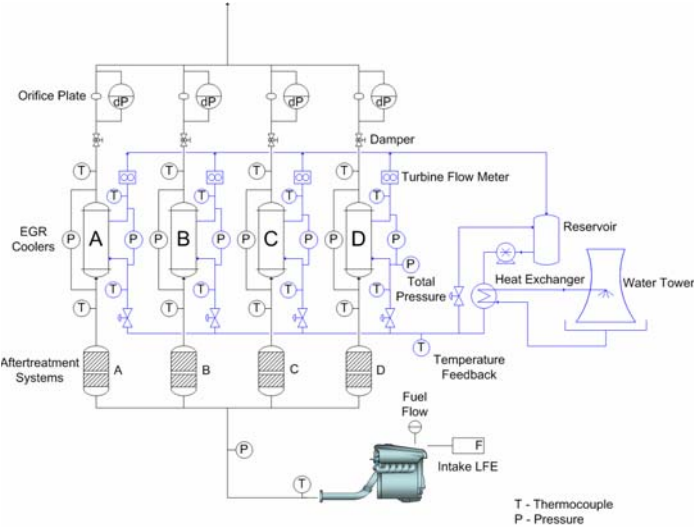


Figure 1. Schematic of Test Cell for EGR Cooler Fouling Study

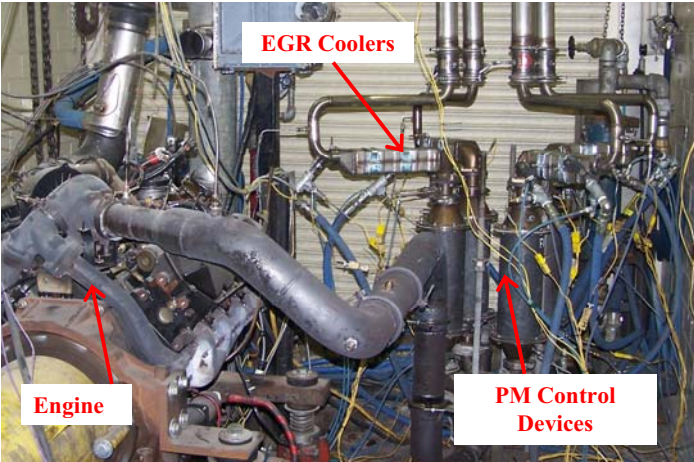


Figure 2. EGR Cooler Fouling Test Bench

The experimental process included a diesel exhaust flow measurement system installed in each of four parallel exhaust legs, branching out from the single diesel engine exhaust pipe. This process relied on flow measurement using thin plate orifices, one in each of the four EGR cooler legs. All four orifice plates were calibrated to measure flow rates in terms of orifice pressure drop, inlet pressure and temperature. The calibrated pressure transducers were used to measure orifice plate pressure drop. To ensure a proper mass balance and check in the system, the total exhaust flow rate was calculated using the measured intake mass air flow and fuel flow rates. A high temperature mechanical valve located downstream of each EGR cooler was used to control the flow. The orifice plates in each of the EGR