Engine Manufacturers Association
www.enginemanufacturers.org
Two North LaSalle Street
Suite 2200
Chicago, Illinois 60602
Tel: 312/827-8700
Fax: 312/827-8737

The Use of Exhaust Gas Recirculation (EGR) Systems in Stationary Natural Gas Engines

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EMA Position

EMA supports the exploration and development of new, cost-effective control systems to reduce emissions from reciprocating engines, including stationary gaseous-fueled engines. Exhaust Gas Recirculation (EGR) is only one of several options currently being considered by EMA members as a potential emissions control strategy. However, any emissions reduction strategy must be thoroughly tested and examined to determine its long-term effects on emissions and the satisfactory operation of the engine itself. Until the necessary research, development and testing of EGR systems are completed, the very limited results regarding emissions from EGR equipped gaseous-fueled engines must be viewed as preliminary and not satisfactory for widespread acceptance.

Introduction

Over the past 40 years, engine manufacturers worldwide have invested significant capital in research and development efforts to improve natural gas reciprocating engine technology. These efforts to improve efficiency and reliability, reduce emissions, and lower costs have provided proven advances in engine power production for many applications, resulting in increased customer value for a variety of applications including baseload and standby electric power generation, natural gas compression, agricultural irrigation and other mechanical drives.

One key advancement, begun in the early 1980's, became known as "lean burn" combustion. Lean burn combustion, using up to 100% excess air, results in significantly lower NOx emissions compared to rich burn combustion which was the prevalent and standard engine technology of the time. Lean burn combustion has the added benefit of improving energy efficiency and life cycle costs for end users. Although more complex and costly to manufacture, lean burn combustion results in engine-out NOx rates that are some 90% lower than rich burn, from 15 grams/bhp-hr to 1-2 grams/bhp-hr, along with a 5-10% fuel economy improvement and up to a 50% reduction in specific maintenance costs.

Major engine manufacturers developed lean burn engines in response to a market demand for improved efficiency, lower costs, and reduced NOx emissions. Lean burn engines are capable of meeting NOx emission limits in most states without expensive aftertreatment devices. Rich-burn engines generally need the addition of three-way catalysts to reduce their inherently higher NOx emissions that result from the rich-burn combustion process. Today, after nearly a quarter century of continuous lean burn development and investment, over 80% of all heavy duty stationary natural gas engine horsepower sold in the US employs lean burn combustion technology, making it the world standard for best combination of low NOx emissions and affordable, durable operation.

Recently, increasingly stringent national ambient air quality standards are forcing air quality regulators to seek even further reductions in NOx emissions from stationary sources, including engines. In areas with poor air quality, such as in several regions of California, regulators are imposing extremely tight emissions standards that require the use of aftertreatment devices even on clean, lean burn natural gas engines. Because of the exhaust gas characteristics, further reductions in NOx emissions from lean burn engines necessitate the use of selective catalytic reduction (SCR) aftertreatment devices to meet these new standards. SCR is an expensive system which greatly adds to the capital and operating costs of lean burn engine systems. Depending on the NOx level established by regulators, stationary engine systems, even with aftertreatment technology, often cannot effectively meet some of the stringent NOx emissions standards being promulgated today.

The Emergence of EGR in Stationary Engine Systems

Because engines are often the best-suited and most cost-effective technology available, or the only feasible option, to produce power for many applications, customers and suppliers are exploring technical options that will allow engine-based systems to operate under extremely low NOx emissions limits imposed by some regulators. Recently, a combustion concept called EGR, or exhaust gas recirculation, has received attention as a potential solution.

The EGR concept was first investigated on stationary, natural gas engines in the US in the early 1980s and, more recently, put forward in Europe. EGR also is being used on many diesel and gasoline mobile sources. EGR employs hardware changes to recirculate engine exhaust into the combustion chamber of a heavy duty natural gas engine as an inert substitute for the excess air normally supplied in lean burn engine operation. EGR allows the combustion chamber to operate as if it were a rich burn engine and, since no excess oxygen is present in the exhaust, a much less expensive nonselective reduction catalyst can be used when aftertreatment is needed to meet further NOx emissions standards.

NOx emissions rates from an EGR and nonselective catalyst equipped engine can be as low as, or lower than, a lean burn engine equipped with the much more expensive selective catalytic reduction (SCR) system, thus making lower installed catalyst cost a key attraction of the EGR concept. This advantage in catalyst cost is the primary driver in promoting EGR systems. Several independent companies have installed retrofit systems on existing natural gas engines and have reported some success in meeting very low emissions requirements during initial and limited field testing.

Most major engine manufacturers are also investigating EGR systems as an alternate combustion technology where the most stringent emissions standards are in place. While lean burn combustion will remain the most attractive choice for most worldwide and US locations, EGR systems could play a role in certain geographic areas where extremely low emissions are required to meet regulatory standards. Although EGR systems are of interest in these areas, previous industry research has shown that these systems have several significant technical issues which need to be fully understood and developed in both lab and field applications before being introduced as a viable and certified option.

EGR Technical Issues

- **Combustion Contamination**. Exhaust gas from any combustion process may have certain contaminants, including acid forming compounds, unburned and partially burned hydrocarbons, air pollutants, and liquid water. These contaminants can be successfully reintroduced into the combustion chamber but may lead, over time, to serious combustion degradation and instability, and shorter component life. Such effects need to be fully understood and documented, and appropriate improvements made to the combustion process to protect the customer's investment and maintain true long-term emissions compliance. This activity would be a key element of any major engine manufacturer's development process.

- **Control System Stability**. Control systems for modern engines have been developed over two decades and involve integrated strategies to adjust air/fuel ratio, ignition timing, and air flow rates to maintain emissions control at varying loads, speeds, and fuel conditions. These systems are at the heart of successful engine operation today and are vital to satisfactory long term operation. Adding EGR into the combustion process introduces further complexity that must be carefully integrated into the entire engine control system approach for successful operation over a wide range of conditions. For instance, if fuel quality changes over time, the air/fuel ratio, ignition timing, air system rates, AND the EGR rate must be adjusted accordingly to keep the combustion system stable and emissions in compliance. On the other hand, if the engine's load changes rapidly from part load to full load and back to part load, the EGR system dynamics must be included in the overall control strategy response to make sure the engine operates smoothly during this transition.

- **Application Variability**. Adding an EGR system to a current engine may seem benign for a steady state, non variable application. However, manufacturers must develop engines that can meet an endless variety of applications which our customers demand, and control systems must be fully developed to accept the addition of an EGR system. In addition, the applicability and effectiveness of EGR will depend on engine size since the addition of EGR will alter an engine's thermal loading and temperature profile. Because of different inlet temperature needs, an EGR application that works on a small engine may not necessarily work on larger or turbocharged engines.

- **Materials and Durability**: EGR systems may decrease long-term life of the components affected, including the EGR coolers and control valves, the pistons and cylinder heads, exhaust manifolds and sensors, as well as the post engine catalyst. Operating a few hundred hours per year may not lead to any significant materials degradation in the overall lifespan of an engine. However, continuous duty applications at 8500 hours per year may cause near term emissions noncompliance and longer term materials breakdown, shorter component life, and even unexpected, catastrophic engine failures. To minimize or eliminate the potentially negative impacts of EGR on engine components, compatible components and designs must be used that often require thousands of hours of lab and field test operation for validation. Although both expensive and time consuming, such efforts are a necessary part of proving any new combustion design including EGR systems. Therefore, major engine manufacturers worldwide need to plan for and execute these tests in order to develop the materials needed for successful EGR applications.

- **Liquid Dropout**. During exhaust gas recirculation, the gasses must be cooled with an external cooler before being reintroduced into the cool inlet manifold of an engine. The cooling process for the EGR may result in liquids being formed in the return lines, depending on temperatures and local humidity, much as liquids are formed in the tailpipe of an automobile at certain conditions. This liquid dropout could be a continuous stream that needs to be carefully understood and managed with the needs of the local environment in mind. While there may be ways to reintroduce this liquid into the combustion process, doing so may create further problems with combustion and lead to other emissions complications and instability. As such, managing liquid dropout needs careful study and development in an integrated development program.

- **Decreased Fuel Economy**. For a non-selective reduction catalyst to properly treat engine exhaust, the underlying combustion must be rich burn. Rich burn combustion is not as fuel efficient as lean combustion, resulting in decreased fuel economy. Also, using exhaust gas recirculation to dilute the air-fuel mixture is inherently less desirable than simply introducing excess air into the combustion chamber. Atmospheric air has a nearly constant quality at specific altitudes worldwide, while exhaust gas can be highly variable depending on the fuel combusted and the changing dynamics and integrity of the combustion system. Since modern engines are highly tuned for optimal performance and fuel economy, any changes to the combustion chamber to accept EGR constituents may contribute to lower fuel economy rates over time.

- **Emission Reduction Questions**. A handful of companies have applied add-on EGR and catalytic reduction aftertreatment systems to stationary engines and reported promising results in terms of emissions reductions. These results are based on short-term tests on select applications and do not necessarily represent expected results from the complete suite of stationary gaseous-fueled engines or applications and duty-cycles on the market today. In addition, the short-term field test results are not adequate to demonstrate whether the reported emissions rates are sustainable over the required certification period or life of the equipment. Consequently, the results must be considered preliminary and most likely are not acceptable for regulatory or certification purposes.

Conclusion

The use of EGR systems on stationary engines involves many technical hurdles that have yet to be understood and overcome. Prudent investments in research, development, and rigorous testing over time are still needed to determine the true value that EGR may provide. Of particular importance will be the development of an integrated materials and engine combustion control strategy for EGR equipped engines that assures the satisfactory operation and long term durability and reliability of the engine.

With the understanding that the necessary engineering work to resolve the many technical issues has not been completed to date, the limited and short-term field testing of engines outfitted with EGR and nonselective catalysts appears to be a promising option to further reduce NOx emissions from gaseous-fueled engines. However, neither the amount nor extent of emissions data currently available are adequate to demonstrate that the low NOx emissions levels observed are sustainable over the life of the engine or can be achieved over the large variety of engine types needed in the stationary market.

Unless and until sufficient testing results are available to demonstrate long-term and broad effectiveness of EGR systems in reducing emissions, regulatory agencies should not consider EGR systems as a feasible and cost-effective emissions control option for stationary engines. In particular, EMA does not believe that the current emissions data and operating experience regarding EGR systems provide the basis to establish national, state, or local regulatory standards or certification limits for stationary engines.