International Review of Applied Engineering Research.
ISSN 2248-9967 Volume 4, Number 3 (2014), pp. 197-202

http://www.ripublication.com/iraer.htm

Investigation of Diesel Engine in Reduction of NOx Emission Using Hollow Fiber Membrane Module

A. Hemnath[1] and E. Britto Sebastiraj[2]

[1]Department of Automobile Engineering, Rajalakshmi Engineering College, Anna University, Thandalam, Chennai, India.
[2] Department of Automobile Engineering, Rajalakshmi Engineering College, Anna University, Thandalam, Chennai, India.

Abstract

NOx in the Diesel engine exhaust gas is closely related to the peak cycle temperature and available amount of oxygen in the combustion chamber, so NOx emissions from diesel engines can be reduced by reducing the peak temperatures of combustion. At present to reduce peak combustion temperature we use EGR. It reduces peak temperature by recirculation of exhaust gas into combustion chamber with intake air and reduces combustion. This paper is about a study of replacing EGR with a Hollow fiber membrane module. This module separates Nitrogen from ambient air and gives Nitrogen enriched air (NEA). NEA is used instead of intake air and avoids EGR usage i.e. Nitrogen is an obvious diluents of heat and it does the work instead of exhaust gas. The effectiveness of NEA for NOx emissions reduction is also related to the composition of NEA. Only slight enrichment is needed and NEA compositions of 80% to 82 % nitrogen range prove to be very effective in NOx reduction. The membrane material used is perfluoropolymer.

Keywords: Hollow fiber membrane (HFM), Nitrogen enriched air (NEA), Exhaust gas recirculation (EGR), Nitrogen-oxides(NOx).

1. Introduction

Oxides of nitrogen is produced in very small quantities can cause pollution. While prolonged exposure of oxides of nitrogen is dangerous to health. Oxides of nitrogen which occurs only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO2). Nitrogen and oxygen react at relatively high temperature. NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The high peak combustion temperature and availability of oxygen are the main reasons for the formation of NOx. The majority of NO formed will however decompose at the low temperatures of exhaust. But, due to very low reaction rate at the exhaust temperature, a part of NOx formed remains in exhaust.

Many theoretical and experimental investigation shows that the concentration of NOx in the exhaust gas is closely related to the peak cycle temperature and available amount of oxygen in the combustion chamber. Any process to reduce cylinder peak temperature and concentration of oxygen will reduce the oxides of nitrogen. The dilution of fuel-air mixture entering the engine cylinder with an inert or non-combustible substance is one which absorbs a portion energy released during the combustion, thereby affecting an overall reduction in the combustion temperature and consequently in the NOx emission level.

A promising new method of reducing NOx emissions involves the recycling of exhaust gas in a process called exhaust gas recycle. EGR sends captured exhaust gas back into the combustion chamber of the engine, thereby increasing fuel economy and reducing emissions: a 25% EGR leads to a 50% reduction in NOx.

There are some problems, however, associated with the process, including:

(1) extra pumping and cooling of the EGR stream,

(2) engine wear from re-circulating engine soot, and

(3) high feed air water vapor levels.

These issues can be avoided by the use of nitrogen-enriched air (NEA), which reduces the diesel combustion temperature and, in turn, the amount of NOx emitted in the engine exhaust. The NOx reductions achieved through NEA are similar to those accomplished through the EGR process, while simultaneously avoiding the pumping, cooling, wear, and water vapor issues associated with EGR. perfluoropolymer membranes used to produce nitrogen enriched air by the turbocharged intake air to inlet of membrane system. Cooled turbocharged air is processed by an NEA membrane to supply NEA to the diesel engine intake. NEA reduces the diesel combustion temperature in turn, the amount of NOx produced and emitted in the engine exhaust is greatly reduced. Membrane modules are designed for very high flux, harsh operating conditions, stable performance, and production of NEA in the range of 79.5% up to 84%.

2. Nitrogen Oxides (NOx)

Nitrogen oxides (NOx) are the various compounds of nitrogen and Oxygen(O_2) formed during the combustion process. Both nitrogen and O2 are present in the air used for combustion. Exposure to NOx can cause respiratory problems, such as lung irritation, bronchitis, or pneumonia. Photochemical smog results when HCs and NOx are combined with sunlight. Smog appears as brownish ground-level haze. Smog can cause many health problems, including chest-pains, shortness of breath, coughing and wheezing, and eye irritation. When NOx in the atmosphere mixes with rain (H_2O), nitric acid (HNO_3) or acid rain is created.

The formation of NOx is the result of high combustion temperatures and pressures. When combustion temperatures reach more than 2,300°F (1,261°C), the N and the O_2 in the air begin to combine and form NOx. Because outside air is 78% N_2, the gas cannot be prevented from entering the engine. Therefore, the only way to control NOx is to prevent N_2 from joining with oxygen during the combustion process. This is done by controlling the temperature of the combustion process.

In the presence of oxygen inside the combustion chamber at high combustion temperatures the following chemical reactions will takes place behind the flame.

$$N_2 + O_2 = 2NO$$
$$N_2 + 2H_2O = 2NO + H_2$$

3. EGR Systems

Most vehicle manufacturers started to provide emission control systems that reduce NOx as early as 1970. The EGR system releases a sample of exhaust gases into the intake's air-fuel mixture. This lowers the peak temperature of combustion and therefore reduces the chances of NOx being formed. The re -circulated exhaust gas dilutes the air-fuel mixture. Because exhaust gas does not burn, this lowers the combustion temperature and reduces NOx emissions. At lower combustion temperatures, the nitrogen in the incoming air is simply carried out with the exhaust gases. Drivability problems can result from having too much re-circulated exhaust gas in the combustion chamber. This is especially true when there is a high demand for engine power. Also, poor control of EGR flow can cause starting and idling problems. This is why EGR flow is disabled during cold starting, at idle, and at throttle openings of more than 50%. There is maximum EGR flow only when the vehicle is at a cruising speed with a very light load.

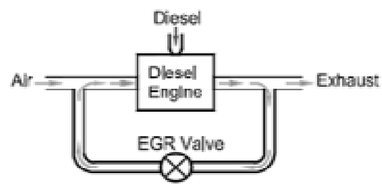

Fig. 1: Exhaust Gas Recirculation.

EGR is equipped with a vacuum-operated valve to regulate the flow of exhaust gas into the intake manifold. Typically, the EGR valve is mounted to the intake manifold. The EGR valve is a flow control valve. A small exhaust crossover passage in the intake manifold admits exhaust gases to the inlet port of the EGR valve. Opening the EGR valve allows exhaust gases to flow through the valve. Here the exhaust gas mixes with the intake air or air-fuel mixture in the intake manifold. This dilutes the mixture so combustion temperatures are minimized.

4. Hollow Fibre Membarane

The hollow fiber (HF) membranes and devices being employed in NEA applications. The HF membranes employed for NEA operate at substantially lower pressure differentials and much higher volumetric gas rates than those applied for industrial nitrogen generation. The Hollow fiber membrane are made of perfluoropolymer fiber.

Thus they can have relatively thin walls, as can be seen in Fig. 2. The perfluoropolymer layer on the outer surface of the porous polymer HF wall forms the separating layer which permeates oxygen preferentially than nitrogen. The high flow rates for the NEA application necessitate large inside diameters and short fiber lengths in comparison to industrial membrane devices to minimize the pressure loss between the air feed and the NEA.

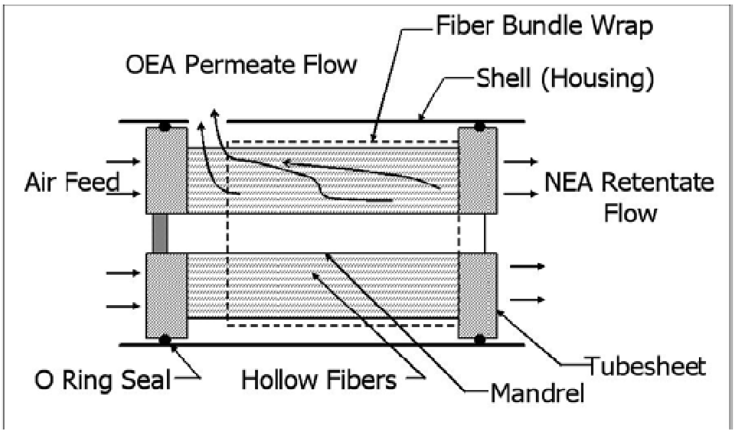

Fig. 2: Cross section of Hollow fiber membrane.

The pressurized air feed passes along the inside of the hollow fibers that are surrounded by atmospheric pressure on their outside diameters. The permeation rates of water vapor, CO_2, and oxygen contained in the air stream are faster than nitrogen and argon and will rapidly diffuse through the fiber walls. The slower diffused nitrogen molecules remain in the fiber bore and are collected as the nitrogen product gas. The air flow rate will determine how much undiffused oxygen remains with the nitrogen gas. The oxygen-enriched air (OEA) is simply exhausted to the atmosphere.

5. HFM Consideration for Diesel Engines

The membranes for the diesel engine have different permeation properties and with less utility when comparing to commercial membrane used in industrial gas separations. Details of an NEA membrane installation on a diesel engine are described in the schematic in Fig. 4. To meet engine application requirements, membranes need to be custom-designed to meet specific engine intake geometry and operating conditions. Membrane housings are being designed of aluminum to accommodate and protect the NEA membrane cartridge in the engine compartment.

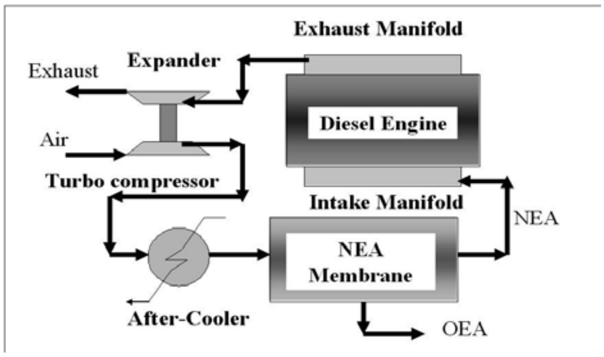

Fig. 3: NEA membrane installation on a diesel engine.

The air charge to the diesel engine is typically pressured by a turbocharger and cooled in an after-cooler before delivery to the intake manifold. Turbochargers typically have compression ratios below 3 but this is adequate to drive the NEA membrane device. Thus the NEA device can ideally be located in the air duct between the after-cooler and the intake manifold. Attention must be given to duct and membrane housing design to minimize any pressure loss between the air feed and the NEA product.

Requirements for the NEA membranes in the application of Diesel engines:

- Low pressure loss in the NEA stream.
- Low loss of volume to the permeate.
- Compact size for incorporation in the intake air system.
- Good transient response.
- Lightweight and suited to engine operating environment and
- Low manufacturing cost.

6. Conclusion

The follow are based on comparison of NEA using Hollow fiber membrane with EGR,

- NEA is a natural mode of reducing NOx emission compared to EGR as well. In this experiment uses only the ambient air, which suits the combustion chamber much better than exhaust gases.
- Though there are many advantages of EGR, however still has some limitation in terms of engine durability, lubrication contamination and causes wear to engine parts but this effect is eliminated in NEA.
- This research is helps to develop the respond to dynamic mode of engine operation which could not possible with EGR technology.
- From the experimental suggestion that the NOx reduction without significant penalty on the brake thermal efficiency and also found intake pressure increases due to turbo charging effect.
- NEA is an absolute heat exchanger and it traps the combustion heat from combustion chamber in a much efficient mode.

- The supplemental addition of NEA to an EGR engine act as an added advantage in reducing NOx emissions.
- The HFM system is operated with much compact inside the Engine room and it satisfy the requirements of automobile application like less size and compact space inside the engine compartment.

References

[1] The book by V.Ganesan, (2007), "Internal Combustion Engines", Tata McGraw hill publications, pp. 482, 497.

[2] Joyce Nelson, Stuart Nemser and Donald Stookey (2003), "DIESEL ENGINE NOX REDUCTION VIA NITROGEN-ENRICHED AIR" Paper presented at American Filtration and Separation Society. meeting, MI American Filtration and Separation Society.

[3] Stork, K.C., and R.B. Poola,(1998), “Membrane-Based Air Composition Control for Light-Duty Diesel Vehicles: A Benefit and Cost Assessment,” Argonne National Laboratory, Technical Report, ANL/ESD/TM-144.

[4] The book by JACK ERAVEC (2010), "AUTOMOTIVE TECHNOLOGY- A System of Approach", Delmar publication, pp. 978–1007.

[5] Stookey and Donald, (2004). " Novel Membrane Systems for Off-Road Diesel Engine NOx Reduction" paper presented in Small Business Innovation Research (SBIR) - Phase I , EPD04009.

[6] Reepen Shah, Hardik Gangadia and Hetal Deshmukh, (2005), "Future Directions Of Membrane Oxygen Separation Technology" Paper presented at ENGINEERING AND TECHNOLOGY JOURNAL OF S.O.C.E.T..

[7] Poola, R.B., R.R. Sekar, and R.L. Cole, (1997), “Variable Oxygen/Nitrogen Enriched Intake Air System for Internal Combustion Engine Applications,” U.S. Patent No. 5,649,517,.

[8] Poola, R.B., K.C. Stork, R. Sekar, K. Callaghan, and S. Nemser,(1998), “Variable Air Composition with Polymer Membrane – A New Low Emissions Tool,” SAE Paper 980178,.

[9] Ladommatos, N., R. Balian, R. Horrocks, and L. Cooper, (1996), “The Effect of Exhaust Gas Recirculation on Soot Formation in a High-Speed Direct-Injection Diesel Engine,” SAE Paper 960841.

[10] Kreso, A.M., J.H. Johnson, L.D. Gratz, S.T. Bagley, and D.G. Leddy,(1998), “A Study of the Effects of Exhaust Gas Recirculation on Heavy-Duty Diesel Engine Emissions,” SAE Paper 981422.

[11] Röpke, S., G.W. Schweimer, and T.S. Strauss,(1995), “NOx Formation in Diesel Engines for Various Fuels and Intake Gases,” SAE Paper 950213.