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A REVIEW OF EGR APPLICATION FOR AUTOMOTIVE INDUSTRY

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A B S T R A C T

Exhaust gas recirculation (EGR) has been widely adopted as an effective strategy to reduce harmful emissions and improve fuel efficiency in internal combustion engines. This review paper aims to provide a comprehensive analysis of the utilization of EGR in various types of internal combustion engines. The review covers the principles of EGR operation, its effects on engine performance, emission reduction capabilities, challenges, and prospects. By evaluating the existing literature and research findings, this paper seeks to offer insights into the potential of EGR as a crucial technology for sustainable and environmentally friendly auto-motive propulsion systems.

1. INTRODUCTION

The automotive industry has long been focusing on reducing the environmental impact of internal combustion engines (ICEs) due to their significant contributions to greenhouse gas emissions and air pollutants. Exhaust Gas Recirculation (EGR) has emerged as one of the most promising technologies to mitigate these challenges. Several factors can explain this unexpected interest. First, the proposed future European rule establishes stricter restrictions for NOX emissions. Second, due to the related adverse effects of other previously utilized solutions, such as high supercharging, an enhanced mix-ing process by more efficient injection systems, etc., further reductions in NOX emissions have likely become the most challenging goal. In addition, higher EGR accuracy and a quicker reaction time in transient settings are now possible because of the development of a new generation of exhaust gas recirculation (EGR) valves and advancements in electronic controls.

Lastly, due to the growth in urban traffic density, most operating circumstances, particularly in passenger vehicles, have shifted to lower engine loads. It must be considered that due to its increased oxygen content, EGR is mostly suggested at partial loads. Last but not least, efforts to minimize emissions in terms of mass rather than concentration have been redirected since the incorporation of particle emission rules in the previous century. These regulations are stricter than those for smoke opacity and can be favored by lowering the exhaust mass flow rate.

2. FUNDAMENTALS OF EGR TECHNOLOGY

Exhaust Gas Recirculation is an emission control technology employed in ICEs to reduce the formation of

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NOx during combustion. The prin-ciple of EGR involves recirculating a portion of the exhaust gas consist-ing mainly of CO2, N2, and steam back into the engine's intake system, where it mixes with the fresh air-fuel mixture before entering the com-bustion chambers. This process dilutes the oxygen concentration in the combustion chamber, leading to a reduction in peak flame temperature, which subsequently lowers the production of NOx. Fig. 1 shows a dia-gram of the EGR system on the engine.

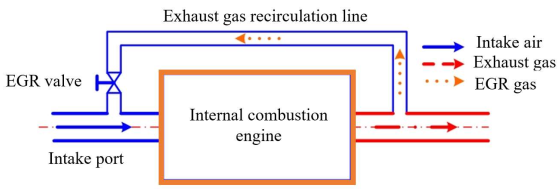

Figure 1. Fundamental of the EGR system in ICEs

Because the heat of the EGR gas is much higher than that of the intake air and thus it increases the specific heat capacity of the intake air, thereby reducing the temperature rise with the same amount of heat released by the combustion process in the chamber. The EGR rate is calculated as follows (Agrawal et al. 2004):

$$\%EGR = \frac{W^t{}_{egr} - W^s{}_{egr}}{W^t{}_{egr}}.100\% \quad (1)$$

where $W^t{}_{egr}$ is the air mass flow without the recirculation and $W^s{}_{egr}$is the air mass flow in case of recirculation.

Furthermore, the EGR rate can be determined based on the CO2 concentration by Baert as follows (Baert, Beckman & Veen 1999):

$$\%EGR = \frac{M'_L}{M_L}.\frac{P_{AC}}{T_{IP}}\frac{P'_{AC}}{T'_{IP}} \quad (2)$$

where M'_L is the air mass flow in case of recirculation; $M_L$is the air mass flow in without the recirculation; P'_{AC} is the intake air pressure in case of recirculation; P_{AC} is the intake air pressure without the recirculation ; T'_{IP} is the intake port temperature in case of recirculation; T_{IP} is the intake port temperature without the recirculation.

EGR application can reduce NOx emissions by prolonging combustion time, increasing specific heat capacity, and diluting the intake gas with inert gas. The extended combustion time hypothesis due to the EGR effect is similar to the reduction of the pre-injection angle. The heat gain hypothesis states that adding an inert gas to the intake gas will increase the specific heat capacity of the reactants in the combustion process, reducing the combustion temperature. According to the intake air dilution hypothesis, the effect of EGR on NOx caused by increasing the amount of unburnt inert gas in the mixture will reduce the adiabatic combustion temperature.

Under high load mode conditions, it is not recommended to perform EGR because it will reduce the combustion process, leading to a rapid increase in smoke and PM. At low load mode, the unburnt HC component in the recirculation gas will be returned to mix with the intake air, thereby increasing thermal efficiency. Part of the recirculated gas returns to the intake manifold, increasing the intake air temperature and affecting the combustion process and exhaust gas composition.

The exhaust gas recirculation technique is very economical to reduce NOx but increases the amount of soot (soot), CO, and HC in the exhaust gas. On this issue, a lot of research has been done. These studies show that PM increases rapidly with more than 50% of circulating gases, so a DPF (Diesel Particulate Filter) should be used. The change in O2 concentration will change the structure of the burning flame and then change the burning time. That shows that reducing combustion temperature is the main factor affecting NO formation.

The implementation of exhaust gas recirculation on diesel engines has some problems, such as: increasing the amount of soot and increasing the amount of PM in the cylinders. When engine parts come into contact at high speeds, scratches caused by these solid particles can result. Sulfuric acid molecules and condensate in the recirculation gas can corrode engine components. Some studies have shown that the damaged cylinder walls reduce the lubricating capacity of the oil because the oil is mixed with soot particles and heavy particles of the circulating gas.

3. EXHAUST GAS RECIRCULATION IN INTERNAL COMBUSTION ENGINES

3.1. Effects of EGR on Engine Performance and Emissions

The effect of EGR rate on NOx reduction at various engine loads at a mid-speed condition. Under all loads, the amount of NOx decreases as the EGR rate increases, as mentioned in Dennis, Garner and Taylor (1999). Because the exhaust gas is recycled, engines with EGR release less exhaust gas than engines with-out it Stumpp and Banzhaf (1978). Thus, even though the volumetric concentration of dangerous compounds in the exhaust gas does not vary, the overall amount of tox-ic material emissions decreases.

Because EGR gas has low concentrations of carbon dioxide and water vapors and a high percentage of oxygen, diesel engines running at low loads can often tolerate a higher EGR ratio. However, when the load increases, the amount of oxygen in the exhaust gas decreases, and the inert components begin to predominate along with a rise in exhaust temperature. As a result of the decreased oxygen availability, diesel engines tend to produce more smoke as the load increases. Wagner et al. used a very diluted intake combination to reduce NOx and soot out-put. Even though PM and NOx emissions reduced dramatically at an extremely high EGR rate (about 44%), this high EGR rate considerably impacted fuel efficiency (Wagner et al. 2003).

Direct injection gasoline engines were used in Sasaki et al.'s trials, and they found that adding the right amount of EGR increased fuel effi-ciency and lowered HC emissions. This behavior was probably brought on by the EGR raising the intake temperature, which helped the flame spread in the comparatively lean area of the unevenly distributed air-fuel mixture (Sasaki et al. 1998). Intake heating in conjunction with EGR at low loads can effectively reduce THC emissions while increasing thermal effi-ciency, according to Kusaka et al. (2000). EGR was also successfully uti-lized in a direct injection spark ignition engine to enhance fuel efficiency (Bai, Wang & Wang 2010, Fontana & Galloni 2010).

Due to changes in each fuel's chemical characteristics under identical working circum-stances, the operating parameters for a specific fuel with optimum EGR rates might not be well suited for the other fuel. Increased compression ratio (CR) resulted in higher brake thermal efficiency and lower specific fuel consumption, according to Kumar, Sekhar and Adinarayana, (2013). The pressure rise rate and thermal efficiency decrease at various compression ratios as the EGR percentile rises, whereas NOX emission rises from 11% to 85%. According to Selim (2003), 5% EGR is beneficial for reducing combustion noise and NOX emission. According to Kumar et al. (2016), CI engines have trouble running on fuels like gasoline, dimethyl carbonate (DMC), and alcohols due to their low cetane number, poor calorific value, high volatility, and latent heat of vaporization. These fuels can, however, be utilized effectively when combined with diesel Kumar et al. (2016). Saleh (2008) discovered that the performance of an LPG-diesel engine (with 70% propane in LPG) increased with applying 5% EGR at part load. In their study of the interaction between EGR and load on LPG-diesel engines, Poonia and Mathur (2012) found that the fluctuation in peak pressure and suggested mean effective pressure in the cycle are lower by up to 60% of load than when the engine is not using EGR.

3.2. EGR application on ICEs fuelled by biofuel

Biodiesel-fuelled diesel engines produce higher NOX emissions despite lower HC, CO, and smoke emissions (Tamilselvan & Nallusamy 2015, Knothe et al. 2006, Annamalai et al. 2016, Tan, et al. 2012). Exhaust gas recirculation (EGR) has proven to be an effective technique in reducing NOX. Using EGR controls and reduces the oxygen concentration and flame temperature of the working fluid in the combustion chamber. At the same time, the reduction in oxygen concentration in the combustion chamber leads to incomplete combustion, which further increases soot emissions (Palash et ao. 2013). Kumar and Kumar (2016) found that using exhaust gas recirculation in a compressed natural gas-jatropha oil methyl ester blend resulted in a substantial reduction in NOX emissions at maximum load conditions when compared to diesel. Agarwal, Singh and Agarwal (2011) investigated the effect of exhaust gas recirculation on diesel engine characteristics, soot formation, and wear of engine main components. They observed lower flame temperature in the combustion chamber due to lower oxygen concentration in the EGR-added fuel/air mixture. Experimental results indicated that significant reduction in NOX emissions. However, there was a considerable increment in hydrocarbons, carbon monoxide, and smoke opacity with EGR concentration rates. Overall, they concluded that 15% EGR concentration was highly effective in minimizing the NOX emissions without much affecting the engine performance characteristics.

Saravanan (2015) investigated the impact of exhaust gas recirculation at various concentrations (10%, 20%, and 30%) in Pentanol-diesel blends on direct injection diesel engines and concluded that the combination of 30% EGR and 45% Pentanol blended diesel fuel simultaneously reduced smoke by 33% and NOX emissions by 57%. However, under all load circumstances of the tested Pentanoldiesel blends, HC and CO emissions rose with increasing EGR rates. It was also noted that the engine performance deteriorated slightly when EGR was used.

Due to the lower flame temperature and greater oxygen availability in the combustion chamber, the EGR approach was one of the most efficient ways to reduce NOX emissions from the diesel engine (Pandian, Sivapirakasam & Udayakumar 2010). The availability of the oxygen concentration was less of a factor in the NOX reduction than the working fluid temperature in the combustion chamber (Tan, et al. 2012). Higher NOX emissions were found when diesel engines were driven with different biodiesels, according to other researchers (Chauhan et al. 2013).

4. CONCLUSION

When using straight diesel as a fuel at lighter loads and using EGR technology, the brake thermal efficiency improves only somewhat as the BSFC falls. However, the efficiency above and BSFC stay unchanged under larger loads. Therefore, a higher EGR rate is preferable at a lower load. With more sophisticated SOI, NOX emission rises, but soot emission falls. As a result, the combined impact of SOI advancement and EGR effectively lowers nitrous oxide gas and carbon particle emission levels. There is a joint rise in work productivity, IMEP, and efficiency. Lower NOX emissions are produced by dual fuel mode than by a straight diesel engine without EGR. NOX emissions are significantly reduced when the EGR is employed in the dual fuel mode and are further reduced as the EGR rate is increased. With the rules of combustion temperatures and pressures, the lower oxygen content reduces the peak pressure rise rate of pre-mixed combustion, leading to decreased NOX and an increase in shoots.

References:

Agarwal, D., Singh, S. K., & Agarwal, A. K. (2011). Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine. *Applied energy*, 88(8), 2900-2907.

Agrawal, A. K., Singh, S. K., Sinha, S., & Shukla, M. K. (2004). Effect of EGR on the exhaust gas temperature and exhaust opacity in compression ignition engines. *Sadhana*, 29, 275-284.

Annamalai, M., Dhinesh, B., Nanthagopal, K., Sivarama Krishnan, P., Lalvani, J. I. J., Parthasarathy, M., & Annamalai, K. (2016). An assessment on performance, combustion and emission behavior of a diesel engine powered by ceria nanoparticle blended emulsified biofuel. *Energy conversion and management*, 123, 372-380.

Baert, R. S., Beckman, D. E., & Veen, A. (1999). Efficient EGR technology for future HD diesel engine emission targets. *SAE transactions*, 381-393.

Bai, Y. L., Wang, Z., & Wang, J. X. (2010). Part-load characteristics of direct injection spark ignition engine using exhaust gas trap. *Applied Energy*, 87(8), 2640-2646.

Chauhan, B. S., Kumar, N., Cho, H. M., & Lim, H. C. (2013). A study on the performance and emission of a diesel engine fueled with Karanja biodiesel and its blends. *Energy*, 56, 1-7.

Dennis, A. J., Garner, C. P., & Taylor, D. H. C. (1999). The effect of EGR on diesel engine wear. *SAE transactions*, 1185-1197.

Fontana, G., & Galloni, E. (2010). Experimental analysis of a spark-ignition engine using exhaust gas recycle at WOT operation. *Applied Energy*, 87(7), 2187-2193.

Knothe, G., Sharp, C. A., & Ryan, T. W. (2006). Exhaust emissions of biodiesel, petrodiesel, neat methyl esters, and alkanes in a new technology engine. *Energy & fuels*, 20(1), 403-408.

Kumar, B. R., Saravanan, S., Rana, D., & Nagendran, A. (2016). Use of some advanced biofuels for overcoming smoke/NOx trade-off in a light-duty DI diesel engine. *Renewable Energy*, 96, 687-699.

Kumar, B. R., Saravanan, S., Rana, D., Anish, V., & Nagendran, A. (2016). Effect of a sustainable biofuel–n-octanol–on the combustion, performance and emissions of a DI diesel engine under naturally aspirated and exhaust gas recirculation (EGR) modes. *Energy Conversion and Management*, 118, 275-286.

Kumar, N. R., Sekhar, C., & Adinarayana, S. (2013). Effects of compression ratio and EGR on performance, combustion and emissions of DI injection diesel engine. *International Journal of Applied Science and Engineering*, 11(1), 41-49.

Kumar, P., & Kumar, N. (2016). Effect of EGR on performance and emission characteristics of a dual fuel engine fuelled with CNG and JOME. *Biofuels*, 7(6), 743-751.

Kusaka, J., Okamoto, T., Daisho, Y., Kihara, R., & Saito, T. (2000). Combustion and exhaust gas emission characteristics of a diesel engine dual-fueled with natural gas. *JSAE review*, 21(4), 489-496.

Palash, S. M., Kalam, M. A., Masjuki, H. H., Masum, B. M., Fattah, I. R., & Mofijur, M. (2013). Impacts of biodiesel combustion on NOx emissions and their reduction approaches. *Renewable and Sustainable Energy Reviews*, 23, 473-490.

Pandian, M., Sivapirakasam, S. P., & Udayakumar, M. (2010). Investigations on emission characteristics of the pongamia biodiesel–diesel blend fuelled twin cylinder compression ignition direct injection engine using exhaust gas recirculation methodology and dimethyl carbonate as additive. *Journal of renewable and sustainable energy*, 2(4), 043110.

Poonia, M. P., & Mathur, Y. B. (2012). Effect of EGR injection rate and engine load on cyclic variations of an LPG diesel dual fuel engine. *Journal of Environmental Research and Development*, 7(2), 746-755.

Saleh, H. E. (2008). Effect of variation in LPG composition on emissions and performance in a dual fuel diesel engine. *Fuel*, 87(13-14), 3031-3039.

Saravanan, S. (2015). Effect of exhaust gas recirculation (EGR) on performance and emissions of a constant speed DI diesel engine fueled with pentanol/diesel blends. *Fuel*, 160, 217-226.

Sasaki, S., Sawada, D., Ueda, T., & Sami, H. (1998). Effects of EGR on direct injection gasoline engine. *JSAE review*, 19(3), 223-228.

Selim, M. Y. (2003). Effect of exhaust gas recirculation on some combustion characteristics of dual fuel engine. *Energy conversion and management*, 44(5), 707-721.

Stumpp, G., & Banzhaf, W. (1978). An exhaust gas recirculation system for diesel engines. *SAE Transactions*, 934-945.

Tamilselvan, P., & Nallusamy, N. (2015). Performance, combustion and emission characteristics of a compression ignition engine operating on pine oil. *Biofuels*, 6(5-6), 273-281.

Tan, P. Q., Hu, Z. Y., Lou, D. M., & Li, Z. J. (2012). Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. *Energy,* 39(1), 356-362.

Tan, P. Q., Hu, Z. Y., Lou, D. M., & Li, Z. J. (2012). Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. *Energy*, 39(1), 356-362.

Wagner, R. M., Green Jr, J. B., Dam, T. Q., Edwards, K. D., & Storey, J. M. (2003). Simultaneous low engine-out NOx and particulate matter with highly diluted diesel combustion. *SAE transactions*, 432-439.

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