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THE IMPACT OF EXHUST GAS RECICULATION (EGR) ON EMISSIONS IN SINGLE CYLINDER GASOLINE ENGINE

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1. INTRODUCTION

The main source of pollution from internal combustion engines is nitrogen oxides and carbon oxides produced by the combustion process of fuel in the engine's combustion chamber, and the exposure to these nitrogen oxides, which is exclusively present in the emissions from engines, comprises a mixture of nitric oxide (NO) and nitrogen dioxide (NO2), both of which pose substantial health risks. Nitric oxide is synthesized within the combustion chamber, specifically in regions characterized by elevated temperatures. Any methodology aimed at diminishing both the peak temperature and the concentration of oxygen present will subsequently lead to a reduction in the production of exhaust emissions.

The quantity of crude oil reserves held by a nation has consistently been regarded as a vital indicator of that nation's strength. The logical rationale for this perception is that oil constitutes the predominant industry that exerts a substantial impact on the global political landscape. This phenomenon results in an incessant demand for hydrocarbons, thereby necessitating perpetual petroleum production on a global scale. Petroleum, extracted from profound depths beneath the Earth's crust, is subsequently refined into an array of valuable products, including gasoline, kerosene, diesel, asphalt, and liquefied petroleum gas (LPG). The World Petroleum Council (WPC) has projected that global consumption exceeds 100 million barrels daily, predominantly driven by engine-related sectors such as automotive, aviation, agriculture, mining, power generation, marine applications, and numerous others.

Our modern society focuses on improving human mobility to allow access to many unexplored areas of the world. This has led to a rapid increase in vehicles powered by internal combustion engines that use fuels like propane, diesel, gasoline, or natural gas. The gasoline engine is the most common engine type worldwide, but it is also a major source of air pollution and smog. While it is important for transportation, the gasoline engine produces exhaust emissions as a result of burning fuel. These emissions include nitrogen (N2), water vapor (H2O), carbon dioxide (CO2), carbon monoxide (CO), unburned hydrocarbons (UHC), and nitrogen oxides (NOx). These chemicals can cause serious health problems over time and can sometimes even lead to death. For instance, carbon monoxide (CO) is a dangerous gas that is colorless, odorless, and tasteless but highly toxic. On the other hand, carbon dioxide (CO2) is one of several greenhouse gases that significantly affects global climate change. When nitrogen oxides (NOx) react with ammonia, they produce particulate matter and nitric acid vapor, which worsens respiratory issues like bronchitis.

1.1 Exhaust gas recirculation system (EGR)

Exhaust gas recirculation system (EGR) is one of the techniques to reduce a nitrogen oxide emission on internal combustion engines. Was firstly adopted in diesel engines, But with the growing energy and environment problems, EGR has been commonly used also in gasoline engines together with other advanced techniques. The advantages of using EGR in gasoline engine solving the problem of reducing nitrogen oxide in exhaust gas emission and its effects to the performance. Reduction of combustion temperature will reduce fuel consumption and prevent fuel enrichment in gasoline engine to inhibit knock.

The primary aim of this research is to ascertain the emission levels of Nitrogen Oxides (NOx), Carbon Monoxide (CO), and Carbon Dioxide (CO2).

This manuscript is conducted within the following parameters:

- This investigation is exclusively concentrated on the application of Exhaust Gas Recirculation (EGR) in a single-cylinder, four-stroke gasoline engine.
- The EGR technology employed in this project utilizes a ball valve mechanism to regulate the flow of EGR.
- The experimental protocol was designed to evaluate the NOx emission characteristics of the gasoline engine while functioning under naturally aspirated intake conditions.
- Conduct separate experiments and analyse the NOx emissions of the gasoline engine in the presence and absence of EGR.

1.2 Drawbacks of Internal EGR

The thermodynamic efficiency of an engine is directly correlated with the peak combustion temperature. It is essential to reduce combustion temperature, as excessively high temperatures lead to increased emissions of nitrogen oxides (NOx), particularly at around 2000 degrees Kelvin, where the formation of NOx escalates significantly. Even when emissions are not a factor, the thermal stresses imposed on the engine establish an upper limit for permissible temperature. As depicted in EGR Figure 1, which illustrates architectures for passenger vehicles, a significant disadvantage of internal EGR is that heat from the exhaust is solely transferred to the intake, resulting in a temperature increase in comparison to external EGR. The primary objective of EGR is to lower the combustion temperature.

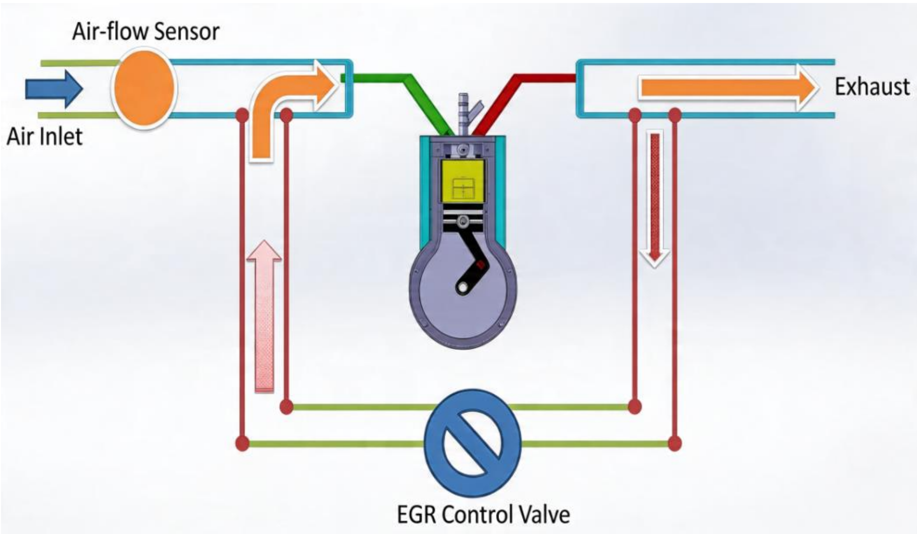

Figure 1 : Sketch of a typical Dual Loop (DL) EGR system

The internal EGR limitation means that engine cooling is necessary, while the external EGR can effectively reduce temperature as heat is released through the piping. Additionally, the combination of elevated cylinder wall temperatures and higher gas temperatures presents another significant issue with internal EGR, leading to engine knock. This occurs when the air-fuel mixture ignites before the spark plug has a chance to ignite the fuel.

2.0 MATERIALS AND METHODS

2.1 Instrumentation and Experimental Set up

The experiments took place using a CUSSONS Engine Test Bed (P8161), which is a four-stroke, spark-ignition engine. The main goal of this study was to compare the exhaust emissions from a standard gasoline-fueled, single-cylinder, four-stroke engine at different speeds and loads with the emissions produced under the same conditions when using an alternative fuel configuration.

We adjusted the engine speed between 1500 rpm and 3000 rpm. During the experiments, we kept track of several important parameters, including the air intake flow rate, and characteristics of the exhaust gas emissions. To make sure our data was reliable and to avoid any interference from exhaust gas recirculation (EGR), we first gathered baseline performance data using regular gasoline under normal operating conditions.

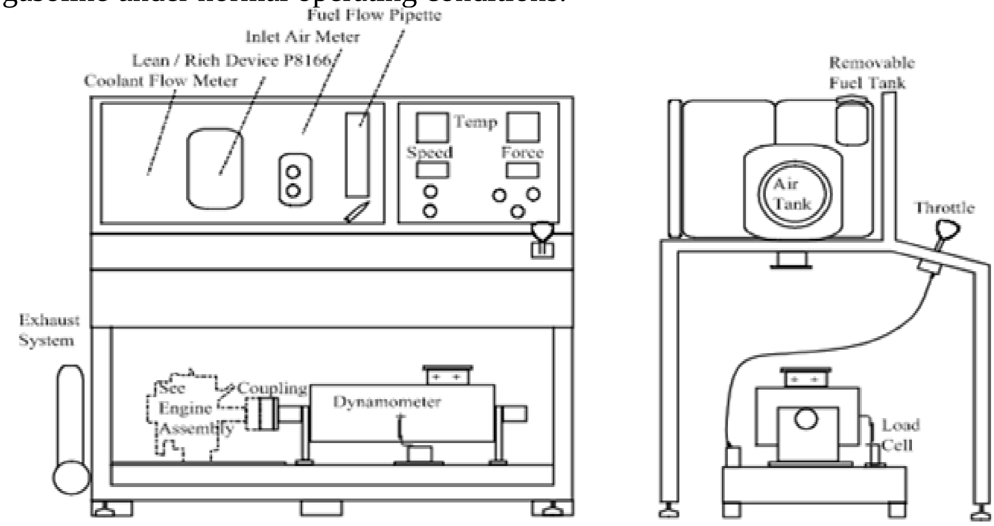

Figure 2: Schematic diagram of a single cylinder engine test bed

2.2 Experimental Procedure

The engine to be used during experiments is a spark ignited gasoline engine. The following steps below explain engine setup:

1. The engine test bed was installed at a well-ventilated place as the engine produce harmful exhaust gases during the engine testing. Otherwise, appropriate ventilation fan and ducting should be installed to discharge the exhaust gases.
2. The engine test bed and control panel were set at a rigged and leveled floor that has adequate strength to support its complete weight.
3. The equipment was inspected to making sure there is no physical damage before the installation.
4. Power supply (220-240VAC/50Hz) was connected to the earth leakage circuit the breaker in the control panel.
5. Connection the power supply and sensors cable from the engine test bed to the control panel.
6. The engine was started.
7. OLIVER K9000 emission analyzer was installed.
8. The engine was run and the results were recorded for exhaust emissions level without and without EGR supply.

2.3 Reduction of NOx

Thermal NOx is created when the nitrogen in combustion air gets oxidized at high temperatures. There are three main mechanisms through which NOx forms:

$N_2 + O \rightarrow NO + N$
$N + O_2 \rightarrow NO + O$
$N + OH \rightarrow NO + H$

2.4 Valves

The EGR valve plays a crucial role in the exhaust gas recirculation system. It regulates the amount of exhaust gas that gets recalculated. You'll find a variety of designs and models for EGR valves, tailored for either petrol or diesel engines, as illustrated in figure 2.4. These valves can be electrically or pneumatically actuated, and some are even linked to the coolant system.

These days, electric EGR valves are the most common choice since they don't require a vacuum or a solenoid valve for their operation.

3.0 METHODOLOGY

This paper aims to explore how exhaust gas recirculation technology works by putting it to the test on a gasoline engine equipped with a valve. The engine we're using is a 4-cycle, air-cooled, single-cylinder model with an overhead camshaft. Specifically, it's the P8161—a 4-stroke, spark-ignited engine with a displacement of 305cc, capable of generating a maximum power of 9.6 BHP (or 7.3 kW) at 3500 rpm, and a peak torque of 18Nm at 2600 rpm.

Table 1: Details Descriptions of the Test S.I Engine

Engine Model	Four Stroke, Spark Ignition
Briggs & Stratton OHV	P8161
Engine type	Single cylinder
Displacement	305 cc
Maximum power at 3600rpm	9.5 BHP (7.1 kW)
maximum torque at 2500rpm	18.5 Nm
Cooling system	Air cooled
Fuel	Petrol
Number of stroke	4
Bore	79.23mm
Stroke	61.67mm
Swept volume	$0.304mm^3$
Cylinder Number	1

3.1 Fabricating the EGR Unit

First off, we measure the diameter of both the air inlet and exhaust exit on the P8161 petrol engine before we get started on the exhaust gas recirculation (EGR) extension. We found that a ball valve with a metal seat, which is 1 inch in diameter, fits nicely into the exhaust exit screw groove along with a downsize nipple. To attach the air intake extension to the downsize nipple, we use a metal belt tie for a secure fit. We also cut a 1-inch hole in the air filter cover to properly secure the downsize nipple. Finally, we connect the downsize nipple directly to the air filter cover using a locking screw head.

3.2 Engine test bed and Instrumentation

The engine test bed is a compact, self-sufficient unit designed for straightforward installation and bench mounting. The standard equipment includes a gasoline engine, which is a single-cylinder, four-stroke, spark-ignited, and air-cooled. This type of small engine is typically utilized in various industrial and domestic settings.

3.3 Mass flow rate

The fuel's mass flow rate can be calculated by measuring the starting weight m_i and the ending weight m_f over a designated time period (t).

Fuel Consumption = $\frac{m_i - m_f}{t}$

3.4 Air flow rate

Air flow rate could be determined by multiplying the cross sectional area of air inlet pipe with air velocity.

Air flow rate $= \frac{\pi d_1^2}{4} * v$

From the derivation of Bernoulli's Theorem, it is shown that the incoming air velocity at the orifice throat:

$$v = \frac{C_v}{\sqrt{1 - \left(\frac{D_2}{D_1}\right)^4}} \sqrt{2\frac{\Delta p}{p}}$$

The displacement volume is the difference between the maximum and the minimum volume. For a single cylinder,

$$V_d = V_1 - V_c$$

$$= \frac{\pi}{4} b^2 sn$$

3.5 Volumetric efficiency

For internal-combustion engines, the volumetric efficiency is defined as the ratio of the actual mass of air drawn in during the suction stroke to the mass of air, which would fill the swept volume of the cylinder at atmospheric pressure and temperature. Volumetric efficiency is only used with four-stroke cycle engines which have a distinct induction process. It is defined as the volume flow rate of air into the intake system divided by the rate at which volume is displaced

$$\eta_v = \frac{V_a}{V_s}$$

Also, we can calculate the volumetric efficiency from the following equation.

$$\eta_v = \frac{2\,\dot{ma}}{ea \times Vd \times N}$$

$$\eta_v = \frac{mep \times Bsfc \times A/F}{\rho_a}$$

AFR is defined as the air mass flow rate divided by the fuel mass flow rate,

$$AFR = \frac{m_a}{m_f}$$

3.6 EGR Ratio

The EGR fraction is defined as the ratio between the mass flow of recirculated exhaust and the total mass flow entering the engine through the intake.

$$\dot{m} = \rho \times A \times V$$

$$EGR_{Ratio} = \frac{\Delta \dot{m}}{\dot{m}_{in}}$$

$$\Delta \dot{m} = \dot{m}_{in} - \dot{m}_{ex}$$

4.0 RESULT AND DISCUSSIONS

4.1 RESULTS.

The engine test was conducted in laboratory, first test is with an objective to analysis the emissions level of with 0% EGR , the second, is with purpose to obtain the emissions level of engine with certain percentage of EGR (10%, 20%, 30%). The Exhaust emissions are evaluated and analyzed from graphs.

4.2 CO emission

Figure 3 shows the dependence of CO emissions on engine speed. This shows the percentage change in carbon monoxide emissions depending on the EGR rate. A higher EGR percentage improves combustion and thermal effects, resulting in lower CO emissions. At 30% EGR, carbon monoxide emissions were minimal.

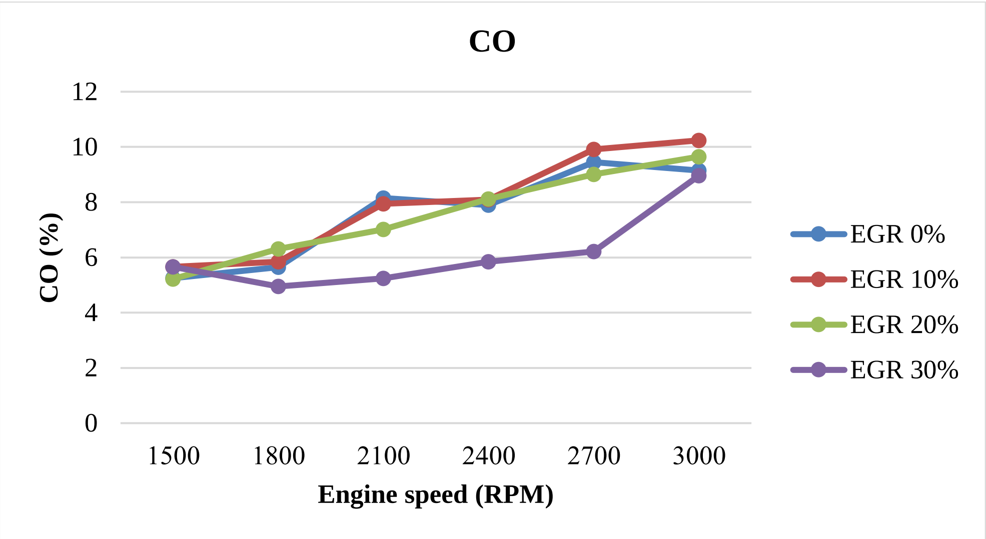

Figure 3 CO emission levels at different Engine Speed

4.3 CO2 emission

Figure 4 shows the dependence of CO2 on engine speed for different EGR systems. The results showed that CO2 emissions increase as EGR increases. CO2 displaces oxygen (O2) in the incoming air, resulting in an increase in intake heat output and an increase in CO2 content in the combustion process.

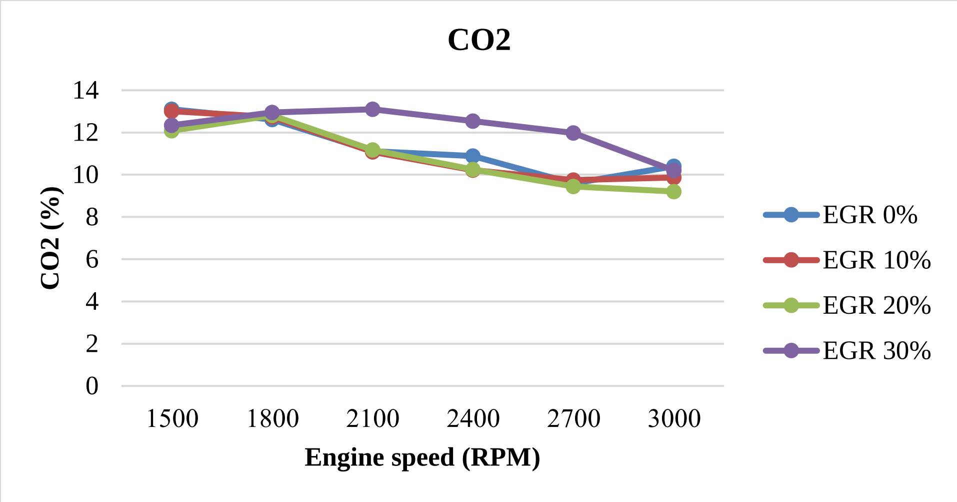

Figure 4 CO_2 emission levels at different Engine Speed

4.4 NOx emission

FIGURE 5 shows the dependence of nitrogen oxides (NOx) on engine speed with changes in the exhaust gas recirculation rate. The results showed that NOx emissions decrease with increasing EGR. EGR increases the diluent content of the unburned mixture, resulting in lower peak combustion gas temperatures and reduced nitrogen oxide production. The unburned mixture in the cylinder consists of both residual gas from the previous cycle and exhaust gas recirculated to the intake side, which acts as a diluent.

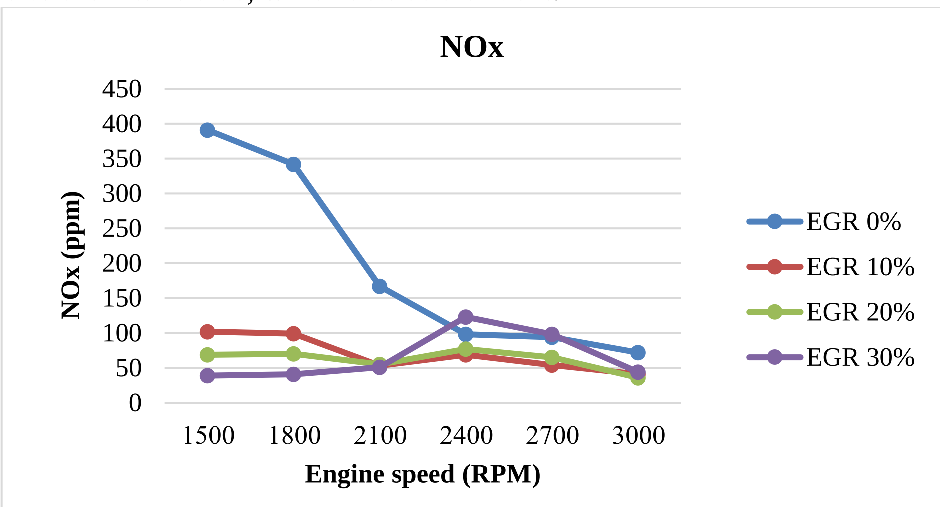

Figure 5 NOx emission levels at different Engine Speed

4.5 HC emission

Figure 6 illustrates the dependence of hydrocarbon emissions on engine speed. This indicates that hydrocarbons change with different EGR rates. As the engine speed increased, the amount of hydrocarbons increased. This is also displayed when EGR is 0%. Due to the high availability of O_2, hydrocarbon emissions are minimized, resulting in an enriched air-fuel composition and a tendency toward complete combustion. The amount of hydrocarbons increases with increasing EGR rate.

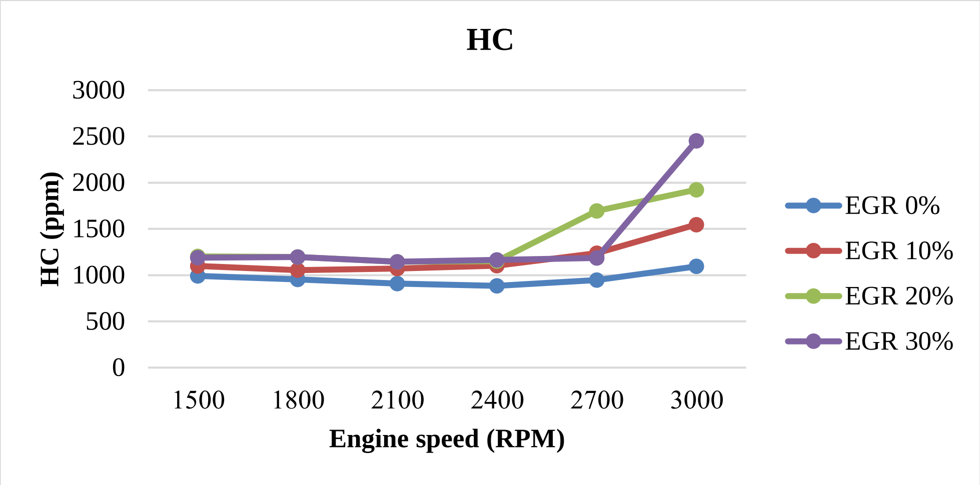

Figure 6 HC emission levels at different Engine Speed

5.0 Conclusion and Recommendations

This study was conducted to investigate post-combustion emission levels and review existing methods for controlling them using EGR. From the experimental analysis, it can be concluded that adding EGR to the intake significantly reduces NOx emissions in a gasoline engine. The duration of NOx can lead to an increase in EGR. It is clear that the extended Zeldovich mechanism of thermal NO production is the mechanism responsible for the majority of NOx produced during the combustion of hydrocarbon fuels at high pressures and temperatures. The rate of NOx production increases exponentially with temperature. In addition, there are many other reactions that lead to the formation of NOx during the combustion of gasoline.

This paper was conducted to investigate post-combustion emission levels and explore methods for controlling them using EGR. The experimental analysis concluded that adding EGR to the intake significantly reduces NOx emissions in a gasoline engine, with the duration of NOx leading to an increase in EGR. It was founded that the rate of NOx production increases exponentially with temperature, alongside other reactions during gasoline combustion. By lowering the flame temperature, EGR effectively reduces NOx production and emissions, and cooling EGR before mixing with the intake gas further enhances this effect. the

We recommend future work incorporate lower engine speeds and detailed analyses, noting that significant NOx reductions are achieved with 10-30% EGR and that cooling the EGR is beneficial for reducing particulate matter.

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