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EFFECT OF EXHAUST GAS RECIRCULATION ON THE EMISSION AND PERFORMANCE OF HYDROGEN FUELED SPARK-IGNITION ENGINE

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Effect of Exhaust Gas Recirculation on the Emission and Performance of Hydrogen Fueled Spark- Ignition Engine

Zuhdi Salhab

Abstract - Exhaust gas recirculation (EGR) is a designed widely used system to reduce the exhaust emissions, particularly nitrogen oxides (NOx). At high temperatures, the nitrogen and oxygen in the engine combustion chamber can chemically combine to form NOx, which, when combined with hydrocarbons and the presence of sunlight, produce an ugly haze known commonly as smog. The EGR system recirculates a fraction of exhaust gases into the intake manifold where it mixes with the fresh incoming charge. By diluting the air- fuel charge, peak combustion temperatures and pressures are reduced resulting in a reduction of NOx concentration. In this paper, an experimental study was conducted to observe the effect of different quantities of EGR on emission and performance of four- stroke single cylinder hydrogen fueled spark- ignition engine with different excess- air ratio. Experiments were carried out for mass flow measuring of EGR with simplifying adjustment (manual designed EGR system) on the engine. Measurement results with higher EGR rates indicate a drastically reduction of NOx, especially with richer mixtures (about 60% NOx reduction). It was also observed an increase in specific fuel consumption of about 8%, a reduction in an indicated mean effective pressure (about 15%) and a reduction in an engine cylinder maximum pressure of about 19%.

Keywords : Hydrogen fueled engine, EGR, NOx emissions, engine performance.

I. INTRODUCTION

The emission problem is one of the most interesting challenges in automotive technology and it is reached at alarming level. Because exhaust pollutants emitted to atmosphere by automobiles are the serious hygienic and environmental risk and the main source of air pollution, particularly in developing countries, the greatest interest and attention was devoted to use an effective technique to reduce the level of these pollutants. So research on improving the engine fuel economy and reducing exhaust emissions has become imperative in combustion and engine development [1].

In internal combustion engines, NOx formation is temperature dependent phenomenon and takes place when the temperature of the charge in the engine combustion chamber exceeds 2000 K [2]. So, to reduce

the NOx emission levels in the exhaust, it is necessary to keep the combustion temperature under control. Exhaust gas recirculation is one of the most effective techniques for NOx reduction.

The literature survey shows many studies of the various effects of EGR on NOx emissions on internal combustion engines (petrol and diesel engines).

II. BASIC EGR OPERATION

The NOx formation is controlled by reducing the temperature in the engine combustion chamber. This temperature is controlled by introducing a metered amount of inert gas into the engine cylinder to partially quench the flame, much like misting barbecue when it flares. It does not put out the fire, but it slows things down a bit. The result is that the fire in the combustion chamber is less intense. Recirculated exhaust gas occupies space that would otherwise contain air. With EGR, the fire is more like a smoldering pile of leaves than a blast furnace [3]. EGR system must precisely control the flow of recycled gases. Too much flow will retard engine performance and cause a hesitation on acceleration. Too little flow will increase NOx and cause engine ping. A well-designed systems will actually increase engine performance and economy [4]. Therefore, the EGR quantity must be controlled.

The EGR systems work with EGR valve which recycles exhaust gases into intake systems. Exhaust gases have already combusted, so they do not burn again when they are recycled. These gases displace some of the normal intake charge. This chemically slows and cools the combustion process by several hundred degrees, thus reducing NOx formation [4]. The decrease in NOx emissions with increasing EGR rate is the result of the following effects:

a) The thermal effect

Increase of inlet specific heats (heat capacities) due to higher specific capacity of recirculated carbon dioxide (CO₂) and water vapor (H₂O) compared with oxygen (O₂) and hydrogen (N₂) at constant pressure resulting in lower gas temperature during combustion process, and particularly in a lower flame temperature [5,6].

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b) *The dilution effect*

A decreasing in inlet oxygen concentration, whose principal consequence is the deceleration of the mixing between oxygen and fuel resulting in the extension of flame region. Also, the gas quantity that absorbs the heat release is also increasing which results in a lower flame temperature [5,6]. As a result, one consequence of the dilution effect is the reduction of local temperatures that can be also considered as a thermal effect (local thermal effect). Another consequence of the dilution effect is the reduction of the oxygen partial pressure and its effect on kinetics of the elementary NO formation reactions.

c) *The chemical effect*

The recirculated H_2O and CO_2 are dissociated during combustion, modifying the combustion process and the NO_x formation. In particular, the endothermic dissociation of H_2O results in a decrease of the flame temperature [5,6].

d) *An increase of the ignition delay*

With EGR rate is generally observed [7], so that the premixed part of combustion is higher, without EGR, it may increase NO_x emissions [8], but in the presence of EGR, the rate of heat release premixed peak is lower, so that it would reduce NO_x emissions.

e) All the combustion process is delayed with diluted air. Consequently, the whole combustion process is shifted further into the expansion stroke, which leads to lower combustion temperature [6].

It is also necessary to mention that the amount of recirculated gases in the combustion chamber depends on the following operating conditions [9]:

1. High EGR flow is necessary during cruising and mid-range acceleration, when combustion temperatures are very high.
2. Low EGR flow is needed during low speed and light load conditions.
3. No EGR flow should occur when it could adversely affect the engine operating efficiency or vehicle driveability (engine warm up, ideal open throttle, etc.). So the main aim of this paper is to investigate and observe some effects of EGR rates on NO_x emissions and engine performance (indicated mean effective pressure, maximum pressure of cylinder charge, and specific fuel consumption).

III. EXPERIMENTAL APPARATUS

All experiments have been performed and conducted on a computerized direct injection, single cylinder four- stroke hydrogen fueled spark- ignition engine (it is also modified to run on gasoline) at the laboratory of Mechanical Engineering Department at Palestine Polytechnic University. All experiments have been realized with various EGR rates at 1500 RPM/100 kPa/15° BTDC.

A fraction of the exhaust gases is to be recirculated back to the engine combustion chamber along with intake air. The quantity of EGR is to be measured and controlled. Because the possibilities available in the laboratory and political conditions did not allow programming the EGR system and engine control unit, a by-pass for the exhaust gases was provided along with the handle (manually) EGR valve to control the quantity of EGR mass flow.

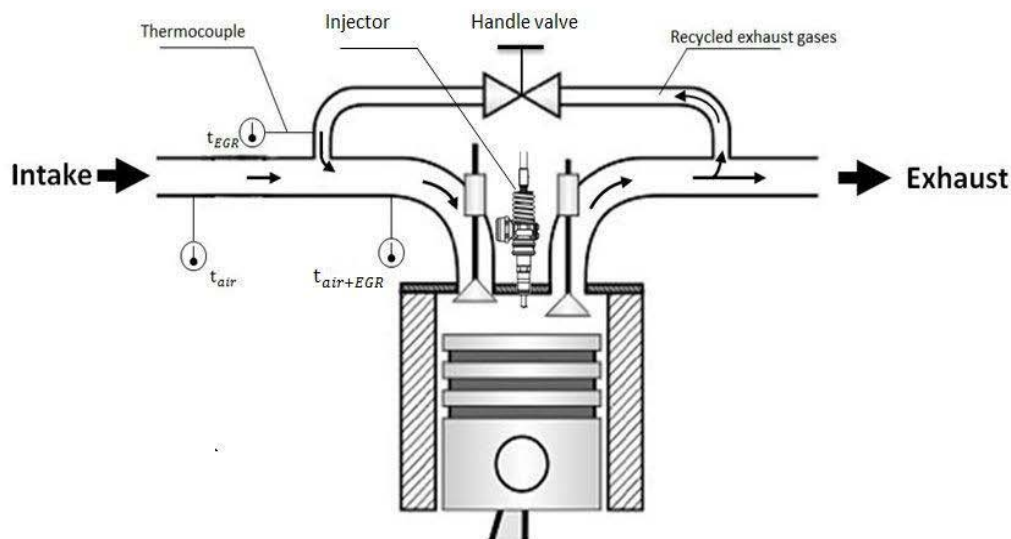


Fig. 1 : A schematic diagram of the proposed EGR system

The engine is coupled with three thermocouples to measure the temperatures of the intake air, EGR, and mixture of air and EGR. A schematic diagram of the components of the EGR proposed system is illustrated in figure 1.

Specifications of the engine are as given in table 1.

Table 1 : Specifications of the engine

Item	Unit	Value
Type of injection	-	Direct
Type of engine	-	OKC-OCTANE
No. of cylinders	-	1
Bore	mm	82.52
Stroke	mm	114.3
Connecting rod length	mm	254.5
Compression ratio	-	10
Engine speed	RPM	1500
Ignition timing	°	-15
Intake open	°	715
Intake closed	°	225
Exhaust open	°	480
Exhaust closed	°	35

The quantity of recycled exhaust gases was calculated by the use of the measured temperatures due to the energy balance equation (at constant pressure) expressed as [10]:

$$C_{P/a} \cdot \dot{m}_a \cdot t_a + C_{P/EGR} \cdot \dot{m}_{EGR} \cdot t_{EGR} = C_{P/m} \cdot \dot{m}_m \cdot t_m$$

Where:

- index m is equal to: $m = a + EGR$,
- $C_{p/a}$: the specific heat of air at constant pressure,
- $C_{p/EGR}$: the specific heat of recycled exhaust gases at constant pressure,
- $C_{p/m}$: the specific heat of the mixture of air and recycled exhaust gases at constant pressure,
- t_a : the temperature of fresh air,
- t_m : the temperature of mixture,
- t_{EGR} : the temperature of recycled exhaust gases,
- \dot{m}_a : air mass flow,
- \dot{m}_{EGR} : recycled exhaust gases mass flow, and
- \dot{m}_m : mixture mass flow.

The values of specific heats were calculated and then the percentage of recycled exhaust gases was determined from the following equation [10]:

$$\% EGR = \frac{\dot{m}_{EGR}}{\dot{m}_{(m_a + m_{EG})}} * 100$$

During measurements the speed of engine was kept constant (1500 RPM) and ignition timing as well (15° BTDC before top dead center). The following parameters were measured:

- Temperatures of EGR, air, and mixture with temperature thermocouples.
- Fuel flow and air flow by digital indicators.
- NOx and excess-air ratio by Sun Diagnostic Gas Analyzer.

The indicated mean effective pressure and cylinder maximum pressure were observed during measurements with different rates of EGR and different values of excess-air ratio. The performance parameters were compared with different EGR and without EGR for same engine operating conditions. The quantity of exhaust gases is recirculated into the engine combustion chamber with air and is achieved with manually controlled EGR valve.

IV. RESULTS AND DISCUSSION

Substantial reduction in NOx concentrations are achieved with 5-15% EGR. 15% EGR was the maximum percentage achieved. The effect of EGR on NOx emissions and engine performance, is similar to addition of excess-air. Both EGR and excess air dilute the unburned mixture. Figure 2 shows the effect of increasing EGR on NOx emissions with excess air. The variation of NOx concentration is a result as the exhaust gases absorb some energy and hence lowers the peak combustion temperature.

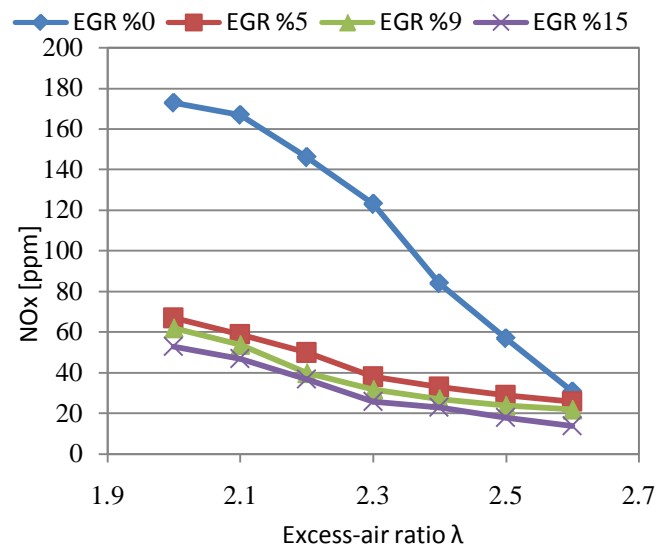


Fig. 2 : NOx vs. excess-air ratio λ with different EGR rates

At low load conditions, very low NOx can be obtained with higher EGR rates and excess air at constant pressure, because the combustion process is delayed due to higher dilution. This is accompanied with an increase of specific fuel combustion (about 8%). And this may be due to the oxygen deficiency which leads to incomplete combustion. Figure 3 shows the variation of indicated specific fuel consumption with excess air and without EGR and 15% EGR.

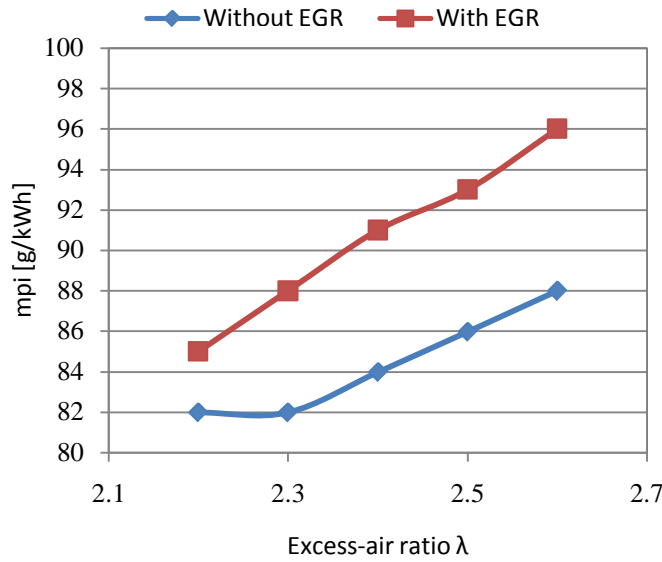


Fig. 3 : Specific fuel consumption as a function of excess-air ratio λ at 0% EGR and 15% EGR

When increasing EGR rate and with extreme lean mixture, the combustion occurs later in the cycle during expansion at a lower in-cylinder temperature, thus reducing combustion speed, the rate of heat release and the value of peak pressure.

Figures 4-5 illustrate the relation of indicated mean effective pressure and maximum pressure of cylinder charge with excess-air ratio λ at 0% EGR and 15% EGR.

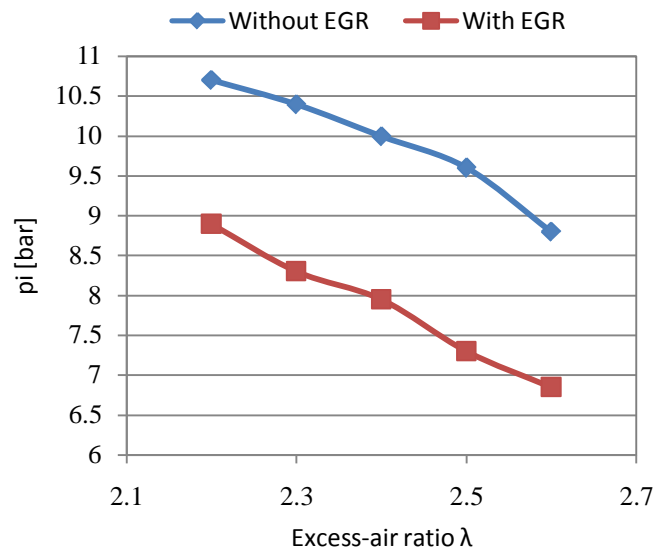


Fig. 4 : Indicated mean effective pressure vs. excess air ratio λ at 0% EGR and 15% EGR

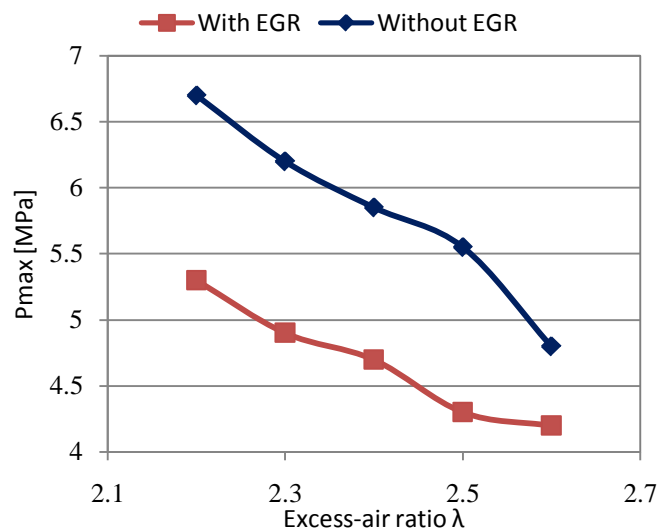


Fig. 5 : Maximum pressure vs. excess-air ratio λ at 0% EGR and 15% EGR

V. CONCLUSION

It can be concluded from the measured results that employing EGR is an efficient technique in internal combustion engines (petrol, diesel, and gas engines) for NO_x reduction as it was seen from figure 2. Further it was also indicated that the engine performance of the engine are slightly independent on EGR. Peak cylinder pressure and indicated mean effective pressure are reduced and ignition delay period was prolonged with 15% EGR.

Further experimental investigations must be done taken into consideration using other engine operating conditions.

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