

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

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*Received: 6 December 2011 Accepted: 3 January 2012 Published: 15 January 2012*

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## Abstract

Exhaust gas recirculation (EGR) is a designed widely used system to reduce the exhaust emissions, particularly nitrogen oxides (NO<sub>x</sub>). At high temperatures, the nitrogen and oxygen in the engine combustion chamber can chemically combine to form NO<sub>x</sub>, 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 NO<sub>x</sub> 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 NO<sub>x</sub>, especially with richer mixtures (about 60

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*Index terms*— Hydrogen fueled engine, EGR, NO<sub>x</sub> emissions, engine performance.

## 1 Introduction

he 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, NO<sub>x</sub> formation is temperature dependent phenomenon and takes place when the temperature of the charge in the engine Author : Department of Mechanical Engineering, College of Engineering & Technology, Palestine Polytechnic University, Palestine. E-mail : zuhdisalhab@ppu.edu. combustion chamber exceeds 2000 K [2]. So, to reduce the NO<sub>x</sub> 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 NO<sub>x</sub> reduction.

The literature survey shows many studies of the various effects of EGR on NO<sub>x</sub> emissions on internal combustion engines (petrol and diesel engines).

## 2 II. Basic Egr Operation

The NO<sub>x</sub> 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

42 down a bit. The result is that the fire in the combustion chamber is less intense. Recirculated exhaust gas  
43 occupies space that would otherwise contain air. With EGR, the fire is more like a smoldering pile of leaves than  
44 a blast furnace [3]. EGR system must precisely control the flow of recycled gases. Too much flow will retard  
45 engine performance and cause a hesitation on acceleration. Too little flow will increase NOx and cause engine  
46 ping. A well-designed systems will actually increase engine performance and economy [4]. Therefore, the EGR  
47 quantity must be controlled.

48 The EGR systems work with EGR valve which recycles exhaust gases into intake systems. Exhaust gases have  
49 already combusted, so they do not burn again when they are recycled. These gases displace some of the normal  
50 intake charge. This chemically slows and cools the combustion process by several hundred degrees, thus reducing  
51 NOx formation [4]. The decrease in NOx emissions with increasing EGR rate is the result of the following effects:  
52 ear 2012 Y Increase of inlet specific heats (heat capacities) due to higher specific capacity of recirculated carbon  
53 dioxide (CO<sub>2</sub>) and water vapor (H<sub>2</sub>O) compared with oxygen (O<sub>2</sub>) and hydrogen (N<sub>2</sub>) at constant pressure  
54 resulting in lower gas temperature during combustion process, and particularly in a lower flame temperature  
55 [5,6].

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

### 3 c) The chemical effect d) An increase of the ignition delay

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

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

67 It is also necessary to mention that the amount of recirculated gases in the combustion chamber depends on  
68 the following operating conditions [9] ). So the main aim of this paper is to investigate and observe some effects  
69 of EGR rates on NOx emissions and engine performance (indicated mean effective pressure, maximum pressure  
70 of cylinder charge, and specific fuel consumption).

## 4 III. Experimental Apparatus

72 All experiments have been performed and conducted on a computerized direct injection, single cylinder four-stroke  
73 hydrogen fueled spark-ignition engine (it is also modified to run on gasoline) at the laboratory of Mechanical  
74 Engineering Department at A fraction of the exhaust gases is to be recirculated back to the engine combustion  
75 chamber along with intake air. The quantity of EGR is to be measured and controlled. Because the possibilities  
76 available in the laboratory and political conditions did not allow programming the EGR system and engine control  
77 unit, a by-pass for the exhaust gases was provided along with the handle (manually) EGR valve to control the  
78 quantity of EGR mass flow. The recirculated H<sub>2</sub>O and CO<sub>2</sub> are dissociated during combustion, modifying  
79 the combustion process and the NOx formation. In particular, the endothermic dissociation of H<sub>2</sub>O results in  
80 a decrease of the flame temperature [5,6]. Palestine Polytechnic University. All experiments have been realized  
81 with various EGR rates at 1500 RPM/100 kPa/15 0 BTDC.

82 ? Temperatures of EGR, air, and mixture with temperature thermocouples.

## 5 ? Fuel flow and air flow by digital indicators. ? NOx and excess-air ratio by Sun Diagnostic Gas

83 Analyzer.

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

88 IV.

## 6 Results And Discussion

89 Substantial reduction in NOx concentrations are achieved with 5-15% EGR. 15% EGR was the maximum  
90 percentage achieved. The effect of EGR on NOx emissions and engine performance, is similar to addition of  
91 excess-air. Both EGR and excess air dilute the unburned mixture. Figure 2 shows the effect of increasing EGR  
92 on NOx emissions with excess air. The variation of NOx concentration is a result as the exhaust gases absorb  
93 some energy and hence lowers the peak combustion temperature. At low load conditions, very low NOx can be  
94 obtained with higher EGR rates and excess air at constant pressure, because the combustion process is delayed

99 due to higher dilution. This is accompanied with an increase of specific fuel combustion (about 8%). And this  
100 may be due to the oxygen deficiency which leads to incomplete combustion. Figure ?? shows the variation of  
101 indicated specific fuel consumption with excess air and without EGR and 15% EGR.

102 Specifications of the engine are as given in table 1. The quantity of recycled exhaust gases was calculated by  
103 the use of the measured temperatures due to the energy balance equation (at constant pressure) expressed as [10]:  
104 The values of specific heats were calculated and then the percentage of recycled exhaust gases was determined  
105 from the following equation [10]:  $m_{EGR} = \frac{C_{p,m} (T_m - T_a)}{C_{p,EGR} (T_m - T_{EGR})}$

106 The following parameters were measured:

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

110  $\phi$  index  $m$  is equal to:  $m = a + EGR$ ,  $C_{p,a}$ : the specific heat of air at constant pressure,  $C_{p,EGR}$ :  
111 the specific heat of recycled exhaust gases at constant pressure,  $C_{p,m}$ : the specific heat of the mixture of air  
112 and recycled exhaust gases at constant pressure,  $T_a$ : the temperature of fresh air,  $T_m$ : the temperature  
113 of mixture, During measurements the speed of engine was kept constant (1500 RPM) and ignition timing as well  
114 (15 0 BTDC before top dead center). Fig. ?? : Specific fuel consumption as a function of excess-air ratio  $\phi$  at  
115 0% EGR and 15% EGR When increasing EGR rate and with extreme lean mixture, the combustion occurs later  
116 in the cycle during expansion at a lower in-cylinder temperature, thus reducing combustion speed, the rate of  
117 heat release and the value of peak pressure. Excess-air ratio  $\phi$

118 Without EGR With EGR Fig. ?? : Maximum pressure vs. excess-air ratio  $\phi$  at 0% EGR and 15% EGR V.

## 119 7 Conclusion

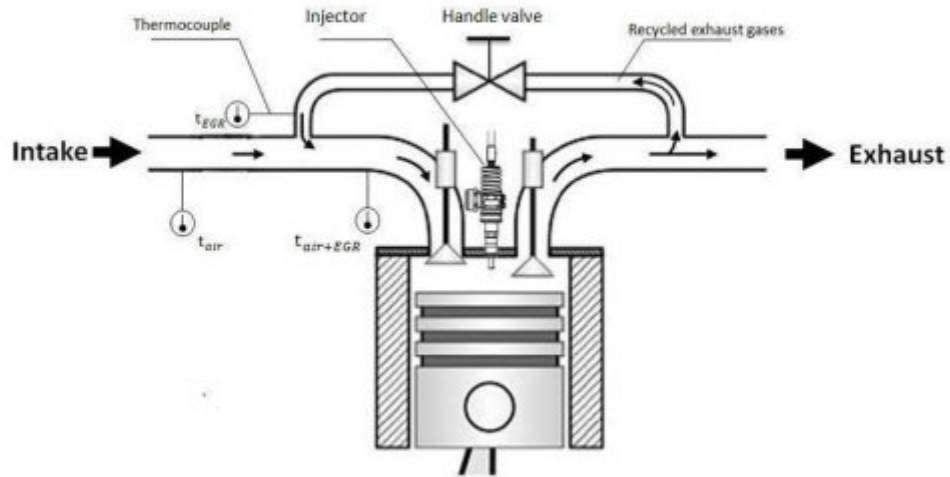
120 It can be concluded from the measured results that employing EGR is an efficient technique in internal combustion  
121 engines (petrol, diesel, and gas engines) for NO<sub>x</sub> reduction as it was seen from figure 2. Further it was also  
122 indicated that the engine performance of the engine are slightly independent on EGR. Peak cylinder pressure  
123 and indicated mean effective pressure are reduced and ignition delay period was prolonged with 15% EGR.  
124 Excess-air ratio  $\phi$

With EGR Without EGR



Figure 1:

## 7 CONCLUSION



1

Figure 2: Fig. 1 :

1

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	o	-15
Intake open	o	715
Intake closed	o	225
Exhaust open	o	480
Exhaust closed		

[Note: o 35]

Figure 3: Table 1 :

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