

Palestine Polytechnic University

College of Engineering



Double Exhaust Gas Recirculation(EGR) System

By :

QASIM AL-TOUS

MOHAMMAD ALI HRINAT

MOUSA AL-HALAQIA

Supervisor :

DR. DIYA ARAFAH

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Dedication (Arabic)

إلى السنبلة الذهبية في بلادي وبيارات البرتقال... إلى كروم العنب و غصن الزيتون... و دم الشهداء و دَمعة الأطفال
..... إلى رغيف الطابون و ريح الزعتر..... إلى (فلسطين). تلك التي صنعتني كي أكون هنا .

إلى الشموع التي احترقت لتصنع لنا غدا أفضل..... (شهداء الحرية).

إلى القابعين خلف القضبان لننعم بطعم الحرية.... (أسرانا البواسل) .

إلى ملاكي في الحياة... إلى معنى الحب و إلى معنى الحنان و التفاني... إلى بسملة الحياة و سر الوجود... إلى من كان
دعائها سر نجاحي و حنانها بلسم جراحي إلى أعلى الحبايب... (امي الحبيبة)

إلى من كلله الله بالهبة و الوقار... إلى من علمني العطاء بدون انتظار... إلى من احمل اسمه بكل افتخار.. أرجو من الله ان
يمد في عمرك لترى ثمارا قد حان قطافها بعد طول انتظار و ستبقى كلماتك نجوم اهتدي بها اليوم و في الغد و إلى
الابد... (والدي العزيز)

إلى من تحلو بالإخاء و تميزوا بالوفاء و العطاء إلى ينابيع الصدق الصافي..... (أصدقائي).

إلى الذين أجدهم معي في السراء و الضراء (أقاربي الأعزاء) .

إلى من سرنا سوياً و نحن نشق الطريق معاً نحو النجاح و الإبداع إلى... (زميلاتي و زملائي)

إلى أولئك الذين يحملون على كاهلهم بناء جيل المستقبل... (أساتذتنا الكرام).

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Abstract:

In internal combustion engine, the temperature of the engine increases because of the repetitive combustion processes inside the combustion chamber and due to Nitrogen atoms react with Oxygen atoms to form Nitrogen Oxides (NO_x), which have a negative effect on plants, human and on Ozone layer especially when Nitrogen Oxides react with Sulfur Oxides to form acid rain, so the cars company made a technique to decrease NO_x by Exhaust Gas Recirculation (EGR).

EGR system works by taking a quantity of exhaust gases (15-30 % by mass flow rate) percent and then entered again into the combustion chamber in order to reduce the temperature of engine and reduce the quantity of NO_x . In the present study a secondary EGR will be connected in parallel with the primary EGR to form Double EGR system in order to reduce the quantity of NO_x compared with traditional system.

The flow rate of the secondary EGR will be controlled separately. Experimental study will be conducted to compare the NO_x and fuel consumption of the Double EGR system. In addition a special device will be used to generate turbulence in the secondary EGR to study the corresponding effect on NO_x .

في محركات الاحتراق الداخلي , درجة حرارة المحرك تزداد بسبب عمليات الاحتراق المتتالية (المتكررة) داخل غرفة الاحتراق نتيجة تفاعل ذرات النيتروجين مع ذرات الاكسجين لتشكيل اكاسيد النيتروجين , التي لها اثر سلبي على النباتات , و الانسان و طبقة الاوزون و خصوصا عندما تتفاعل اكاسيد النيتروجين مع اكاسيد الكبريت لتشكيل الامطار الحمضية , لذلك قامت شركات السيارات بعمل تقنية لتقليل اكاسيد النيتروجين بواسطة نظام اعادة تدوير غازات العادم.

نظام اعادة تدوير غازات العادم يعمل عن طريق أخذ كمية من غازات العادم بنسبة (15-30)% بعد تبريدها و ادخالها مرة اخرى الى غرفة الاحتراق لتقليل درجة حرارة المحرك , و تقليل كمية اكاسيد النيتروجين , في الدراسة الحالية سيتم توصيل نظام اعادة تدوير غازات العادم ثانوي بالتوازي مع الاولي لتشكيل نظام اعادة تدوير غازات العادم المزدوج لتقليل كمية اكاسيد النيتروجين مقارنة مع النظام التقليدي.

معدل تدفق نظام اعادة تدوير غازات العادم الثانوي يتم تحكم فيه بشكل منفصل , و ستجري دراسة التجريبية لنقارن الاداء لنظام اعادة تدوير غازات العادم المزدوج بالإضافة الى استخدام جهاز خاص لتوليد الدوامات في نظام اعادة تدوير غازات العادم الثانوي و في مقابل التأثير على اكاسيد النيتروجين.

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Chapter 1: Introduction

1.1 Importance of the Study:

In Diesel engines the increase of combustion chamber temperature is due to successive cycle and therefore incomplete combustion will occur as a result of incomplete combustion, Nitrogen Oxides (NO_x) will be produced, which have a negative impact on the environment.

The commonly used techniques to reduce Nitrogen Oxides are: exhaust gas recirculation (EGR), water injection, combustion optimization.

The common used technique is Exhaust Gas Recirculation (EGR) in which a specific amount (15-30%) percent by mass of exhaust gases re-circulated into the intake manifold.

The EGR will lead in reduction of temperature in the combustion chamber, therefore, a decrease in NO_x .

1.2. Study Objectives:

In the present project, the effect of increasing EGR amount on NO_x will be studied, this will be accomplished by adding a secondary EGR to create double EGR system and the effect of the double EGR system on NO_x will be experimentally investigated.

1.3 Motivation of Study:

NO_x have negative impacts on the plants, human and the environments. On the plant NO_x impedes its growth. On human NO_x produce unpleasantly smell and some people may be sensitive and it has negative effect on respiratory system. On the environment NO_x react with SO₂ to produce acid rain. Therefore reducing NO_x level becomes an important issue in modern engines.

1.4 Expected Budget:

The expected budget that will use in the project is shown in table 1.1.

equipment's	Cost (\$)
Three valves (ball valves)	60
Battery	150
Pipe fittings	20
Diesel fuel	70
Volumetric flaks	10
Total	310

Table 1.1: Expected Budget.

1.5 Time Table for the first semester:

The time table that will spend during the first semester as shown in table 1.2.

Number of weeks task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selecting idea	■	■	■	■												
literaturereview					■	■	■	■								
Proposed design									■	■	■	■				
Writing report													■	■		
Make presentation															■	■

Table 1.2: Time Table for the first semester.

1.6 Time table for the second semester:

The time table that will spend during the first semester as shown in table 1.3.

Number of weeks task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Searching for motor	■	■	■	■	■	■	■	■								
Bringing tools									■	■						
Make the project											■	■	■	■		
Writing report													■	■	■	
Make presentation															■	■

Table 1.3: Time Table for the second semester.

Chapter 2: State of the Art

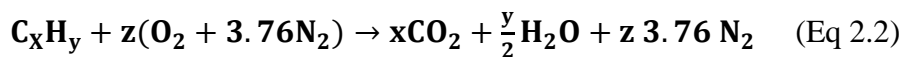
2.1 Combustion of a Hydrocarbon Fuel:

Stoichiometric combustion of simple hydrocarbon in Oxygen forms Carbon Dioxide (CO₂) from all of the Carbon and water (H₂O) the hydrogen, generally, the chemical equation for stoichiometric combustion of a hydrocarbon in oxygen is:



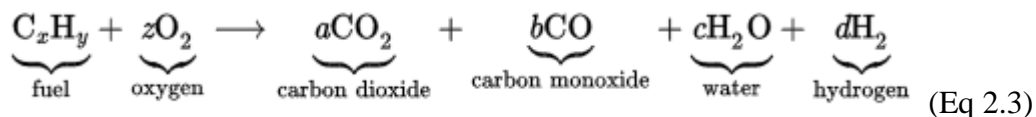
where $z = x + y/4$ [1].

If the stoichiometric combustion takes place in air as the Oxygen source, the Nitrogen present in the air can be added to the equation (although it does not react) to show the composition of the resultant:



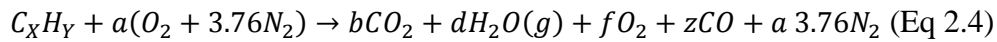
where $z = x + 1/4y$ [1].

The incomplete (partial) combustion of a hydrocarbon with Oxygen produces a gas mixture containing mainly CO₂, CO, H₂O and H₂. The general reaction equation for incomplete combustion of one mole of a hydrocarbon in oxygen is:



The products of incomplete combustion can be calculated with the aid of a chemical balance, together with the assumption that the combustion products reach equilibrium. For example, in the combustion of one mole of propane (C₃H₈) with four moles of O₂, seven moles of combustion gas are formed and z is 80% of the stoichiometric value[1].

Incomplete combustion of a hydrocarbon in air is governed by the following Equation



In general incomplete combustion is studied using the Air Fuel Ratio parameter (AFR), the exhaust gases products vary as a function of AFR for fuel as shown in Figure 2.1.

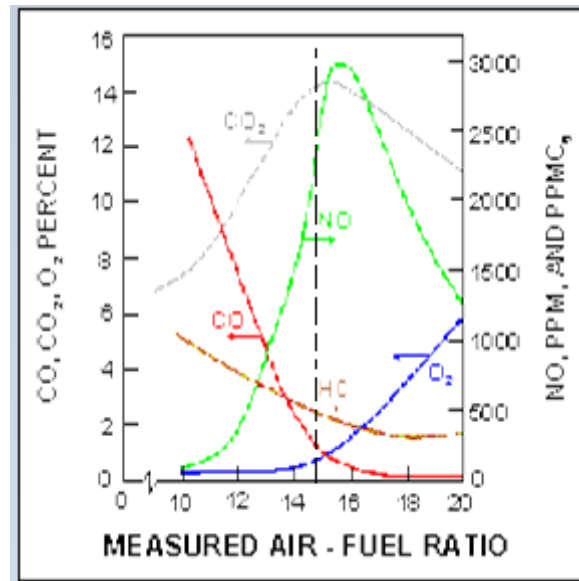


Figure 2.1: Exhaust gases as a function of AFR [7].

2.2 Exhaust Gases Recirculation:

Exhaust gas recirculation (EGR) is an emission control technology allowing significant NO_x emission reductions from most types of diesel engines. Exhaust Gas Recirculation is an effective method for NO_x control. The exhaust gases mainly consist of Carbon Dioxide, Nitrogen, and the mixture has higher specific heat compared to atmospheric air.

Re-circulated exhaust gas displaces fresh air entering the combustion chamber with Carbon Dioxide and water vapor present in engine exhaust. As a consequence of this air displacement, lower amount of oxygen in the intake mixture is available for combustion. Reduced Oxygen available for combustion lowers the effective air–fuel ratio, this effective reduction in air–fuel ratio affects exhaust emissions substantially.

In addition, mixing of exhaust gases with intake air increases specific heat of intake mixture, which results in the reduction of flame temperature. Thus combination of lower Oxygen quantity in the intake air and reduced flame temperature reduces rate of NO_x formation reactions[1].

2.3 EGR Principle of Operation:

To recirculate exhaust gases back into the intake manifold, a small calibrated "leak" or passageway is created between the intake and exhaust manifolds as shown in figure 2.2. Intake vacuum in the intake manifold sucks exhaust back into the engine. But the amount of recirculation has to be closely controlled otherwise it can have the same effect on engine performance and drivability.

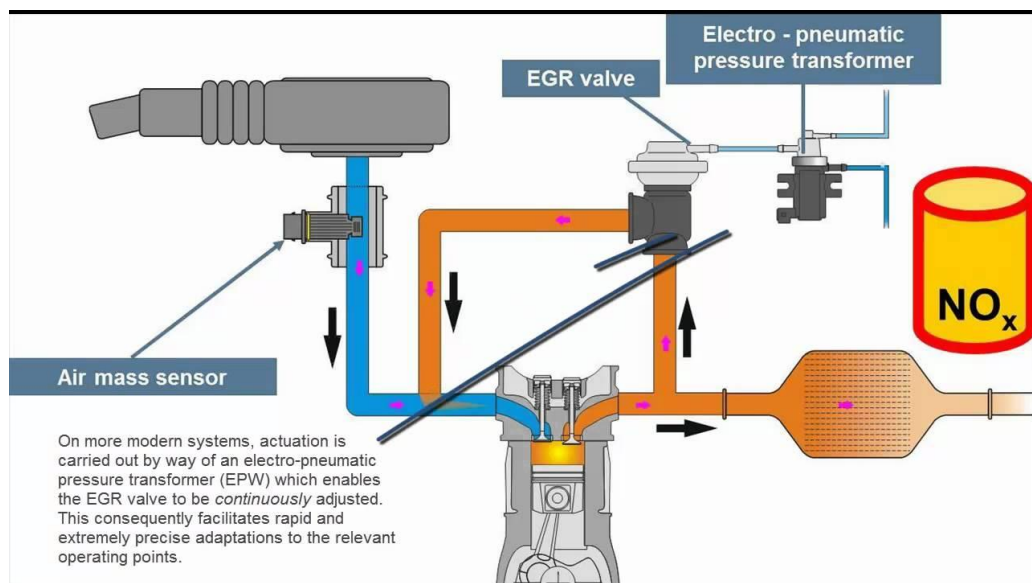


Figure2.2:EGR Principle of Operation of [5].

2.3.1 Effects of EGR on NO_x :

The trends of NO_x emissions with EGR rate are shown in figure 2.3. For all three operating conditions, NO_x concentrations decrease with increasing EGR. Compared to the other two conditions, the initial emission level and the rate of NO_x reduction are much greater at 1200

RPM - mid load, and both efficiency and Nitric Oxides emission trends would benefit from improved boosting technology at low speed - mid load.

The traditional assumption is that increasing engine boost, and subsequently peak cylinder pressures results in increased NO_x emissions. The curves given in figure 2.3 shows that the effect of residual gas far exceeds the potential impact of increased boost on NO_x. Furthermore, the slopes of the trend-lines corresponding to engine operation at 1800 RPM-mid load and 1200 RPM - low load are almost the same, thus indicating that there is no apparent relationship between increased pressure in the cylinder at 1800 RPM and changes in NO_x emissions.[3]

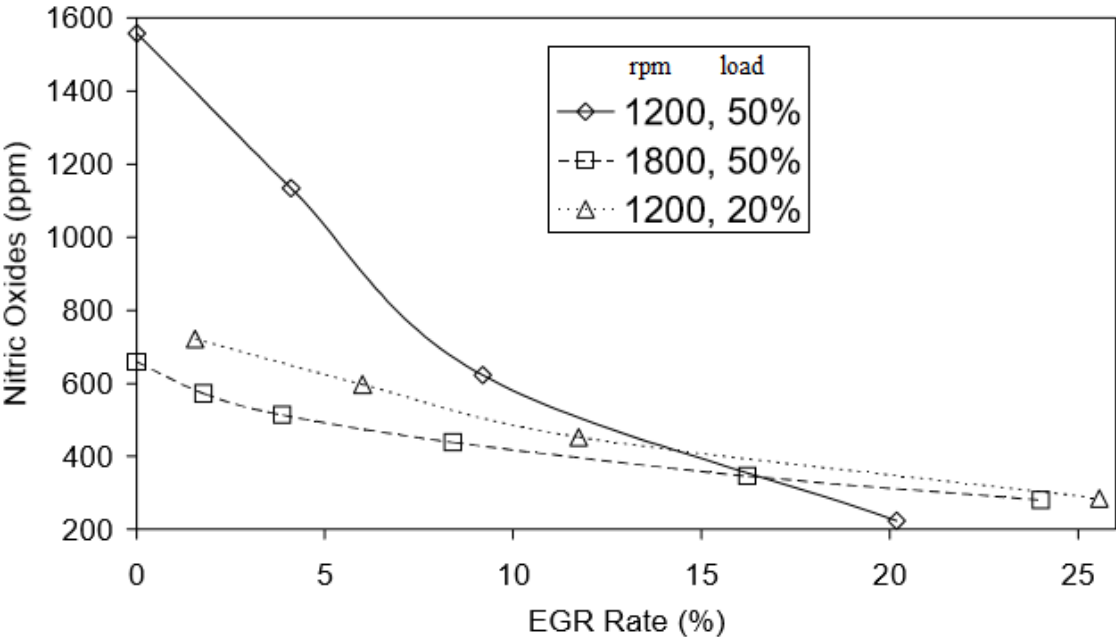


Figure2.3: Nitric Oxide emissions versus EGR Rate[3].

2.3.2 Effect of EGR on Other Emissions:

In addition to NO_x emissions, Unburned Hydrocarbon (HC) and Carbon Monoxide (CO) emissions will be affected by EGR rate as shown in Figure 2.4 with dramatically increased CO and HC levels above 10% EGR. The other two conditions, characterized by higher overall A/F levels, demonstrate almost no change in HC or CO levels with EGR[3].

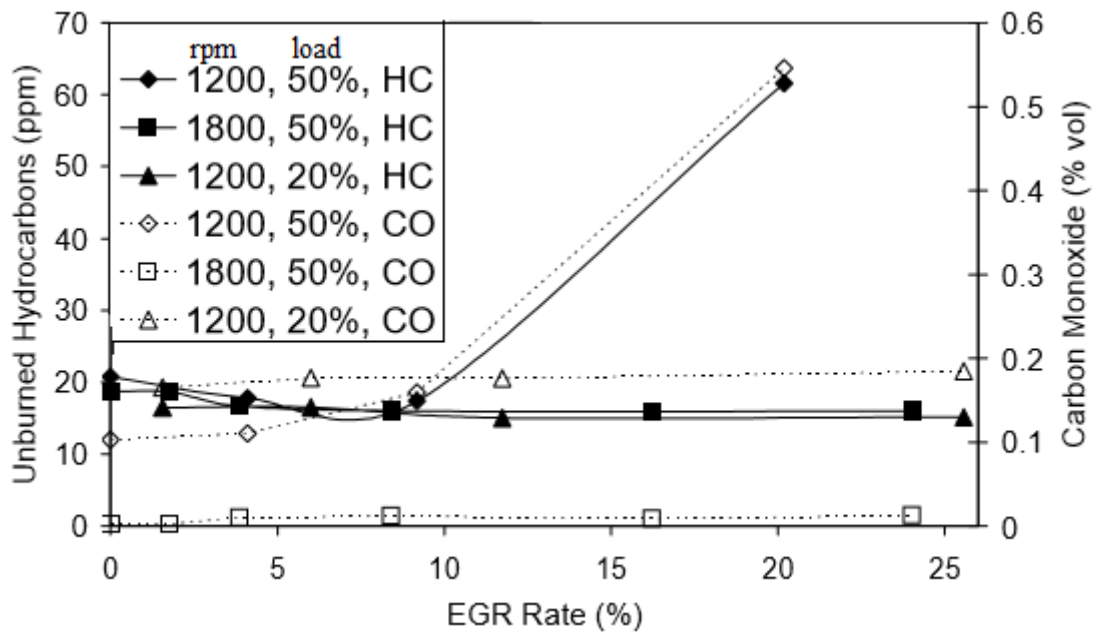


Figure 2.4: The effect of EGR rate on HC and CO[3].

2.4 EGR Configurations and Type:

The configuration of an EGR system depends on the required EGR rate and other demands of the particular application as shown in figure 2.5.

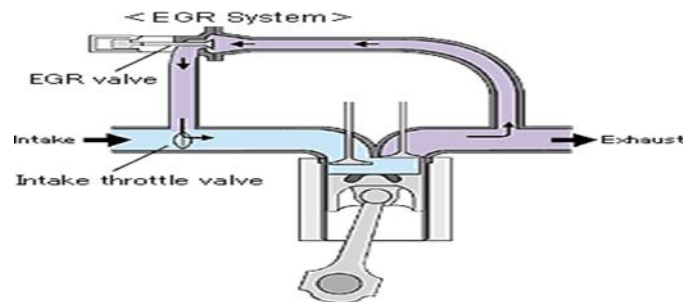


Figure 2.5: Simple EGR System.

The main components of EGR system include:

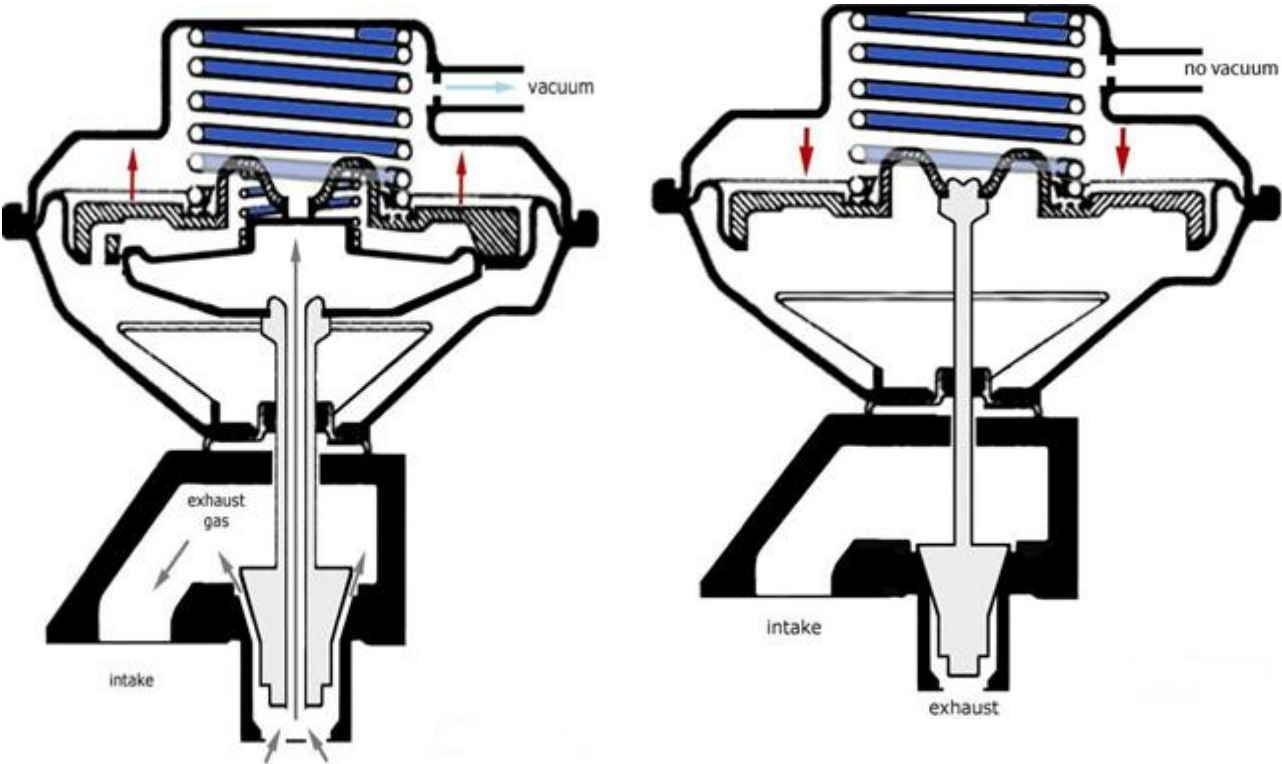
- Control Valve.
- Vacuum Modulator.
- Vacuum Switching Valve.
- Sensors and Electric Control Unit (ECU) [7].

Most older EGR systems use a vacuum regulated EGR valve while newer vehicles tend to have an electronic EGR valve to control exhaust gas recirculation. When the engine is idling, the EGR valve is closed and there is no EGR flow into the manifold. The EGR valve remains closed until the engine is warm and is operating under load. As the load increases and combustion temperatures start to rise, the EGR valve opens and starts to leak exhaust back into the intake manifold. This has a quenching effect that lowers combustion temperatures and reduces the formation of NO_x .

In general there are two commonly used types of EGR system: Mechanical and Electrical EGR System as will be discussed in the sections below.

2.4.1 Mechanical EGR System:

The mechanical EGR system can be classified according to the operating pressure that regulates the EGR flow rate as shown in figure 2.6.



a) Positive back pressure EGR valve

b) Negative back pressure EGR valve

Figure 2.6: Mechanical EGR System[8].

Also Mechanical EGR systems can be classified on the basis of the location of EGR recirculation as follows.

a. Low Pressure Route System:

The passage for EGR is provided from downstream of the turbine to upstream side of the compressor as shown in figure 2.7. The advantages associated with this system are: reduced control complexity, Fuel economy.

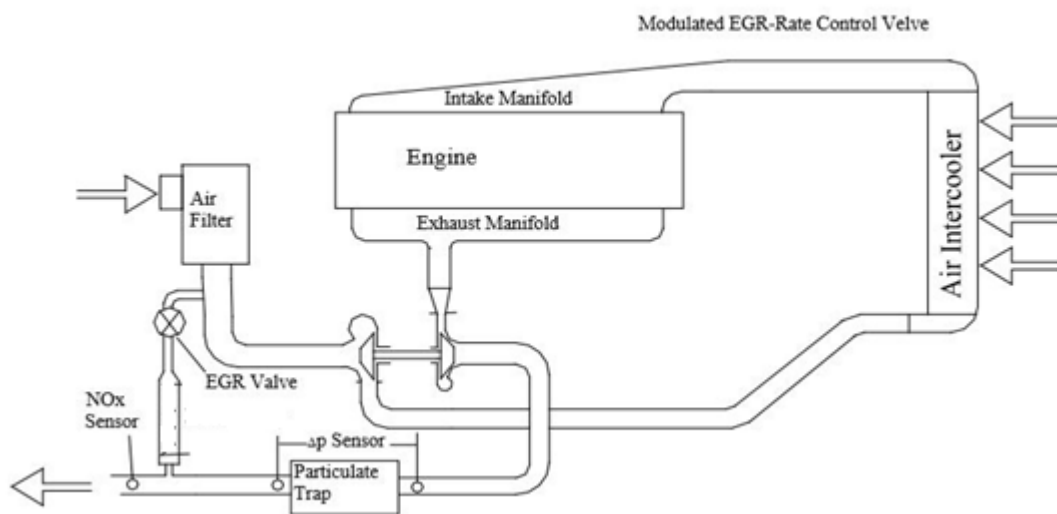


Figure 2.7: Low Pressure Route System [2].

b. High Pressure Route System:

The EGR is passed from upstream of the turbine to the downstream of the compressor as shown in the figure 2.8

The basic advantages of this system are: since EGR is not passed through compressor or intercooler, the problems of durability and reliability are not there, the particulate trap is optional.

But the problems that may arise are: system contamination, increased soot-in-oil, transport losses increase, Complicated variable geometry turbocharger (VGT) -EGR control.

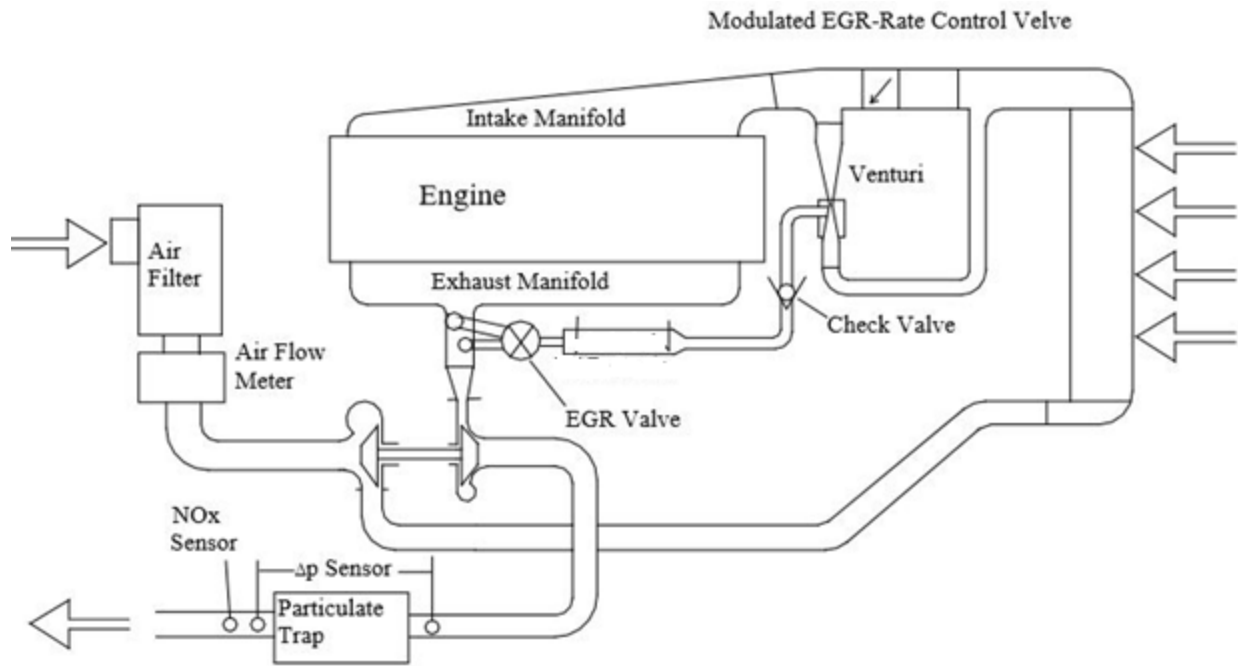


Figure 2.8: High Pressure Route System[2].

2.4.2 Electrical EGR System:

Another type of EGR valve is the electric EGR. This type uses a small computer-controlled stepper motor to open and close the EGR valve instead of vacuum. The advantage of this approach is that the EGR valve operates totally independent of engine vacuum. It is electrically operated and can be opened in various increments depending on what the engine control module determines the engine needs at any given moment in time.

Linear EGR may also be equipped with an EGR Valve Position (EVP) sensor to keep the computer informed about what the EGR is doing as shown in figure 2.9. The EVP sensor also helps with self-diagnostics because the computer looks for an indication of movement from the sensor when it commands the EGR to open or close. The sensor works like a throttle position sensor and changes resistance. The voltage signal typically varies from 0.3 (closed) to 5 volts (open).

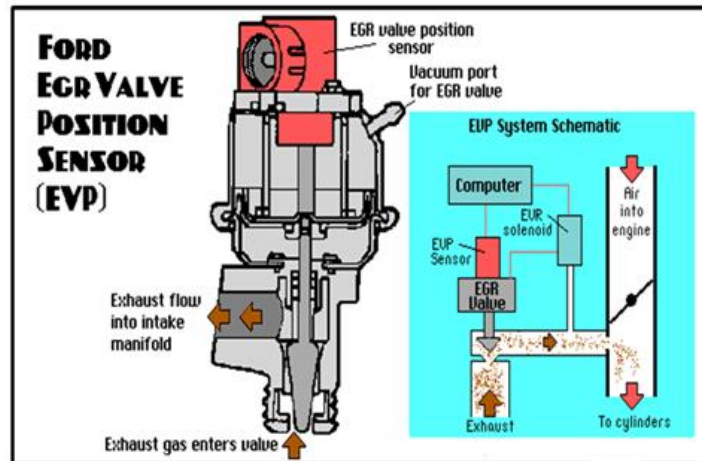
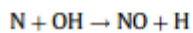
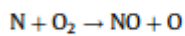
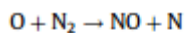


Figure2.9: Electrical EGR[5].

2.5 EGR LiteratureReview:

2.5.1 Agarwal D. [2011]:

NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The NO formation and decomposition inside the combustion chamber can be described by extended Zeldovich Mechanism. The principal reactions at near stoichiometric fuel–air mixture governing the formation of NO from molecular Nitrogen are[1]:



(Eq 2.5) In the first reaction di-Nitrogen is attacked by O to form NO and a Nitrogen radical.

The Nitrogen radical then attacks O₂ to form another NO and regenerates the Oxygen radical.

The initial rate controlled NO formation (when [NO]/ [NO₂] << 1) can be described by the equation:

$$\frac{d[\text{NO}]}{dt} = \left(\frac{6 \times 10^{16}}{T^{0.5}} \right) \exp \left(\frac{-69,096}{T} \right) [\text{O}_2]_e^{0.5} [\text{N}_2]_e \text{ mol s/cm}^3 \quad (\text{ Eq 2.6 })$$

In the expression, [NO] denotes the molar concentration of the species and [O₂] and [N₂] denotes the equilibrium concentration.

The EGR (%) is defined as the mass percent of the recirculated exhaust (M_{EGR}) in the total intake mixture (M_i):

$$\text{EGR}(\%) = \frac{M_{\text{EGR}}}{M_i} \times 100 \quad (\text{Eq 2.7})$$

2.5.1.1. Experimental Setup and Methodology:

A two-cylinder constant speed diesel engine generator set was chosen to study the effect of EGR on the performance and emissions, Carbon deposits, and wear of diesel engine components.

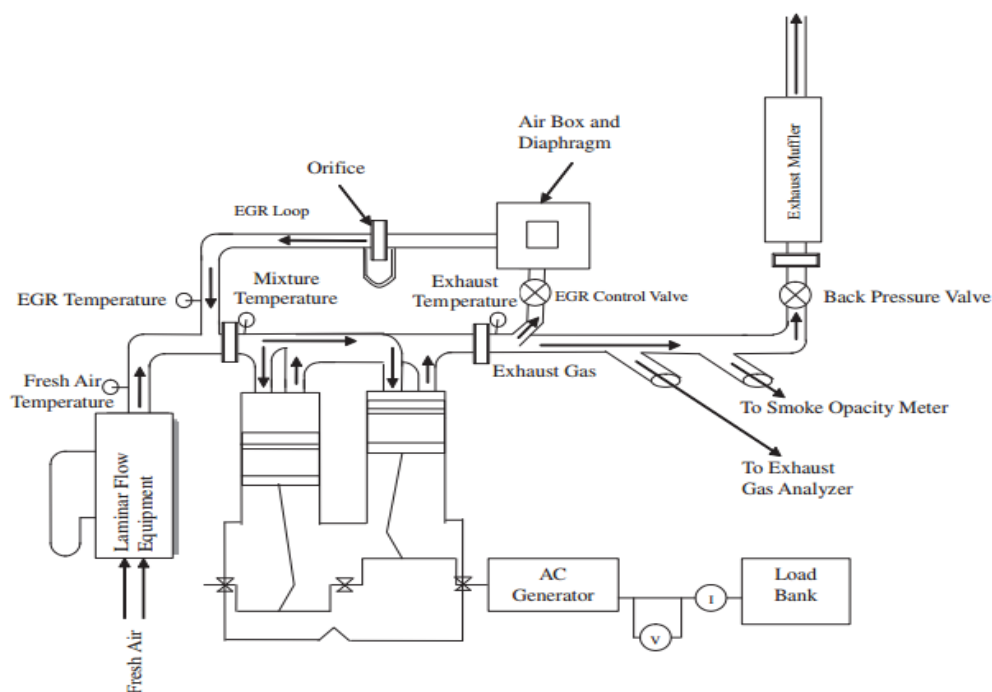


Figure 2.10: Schematic diagram of engine setup using EGR.

The engine was run on different loads at 1500 rpm with different EGR rates (from 0% to 20%) to investigate the effect of EGR on engine performance and emissions.[1]

2.5.1.2 Engine Performance Analysis:

Thermal efficiency is found to have slightly increased with EGR at lower engine loads. The possible reason may be re-burning of hydrocarbons that enter the combustion chamber with

the re-circulated exhaust gas. At part loads, exhaust gas has less CO₂ and fairly high amount of O₂, when exhaust gas is re-circulated in the cylinder, the unburned HC in exhaust gas burns because of sufficient O₂ available in combustion chamber and reasonably high intake temperatures. At higher engine loads, the thermal efficiency remains unaffected by EGR. At higher loads, exhaust gas has higher amount of CO₂, which reduces maximum temperature in combustion chamber along with Oxygen availability therefore re-burning of HC is not significant as shown in figure2.11.

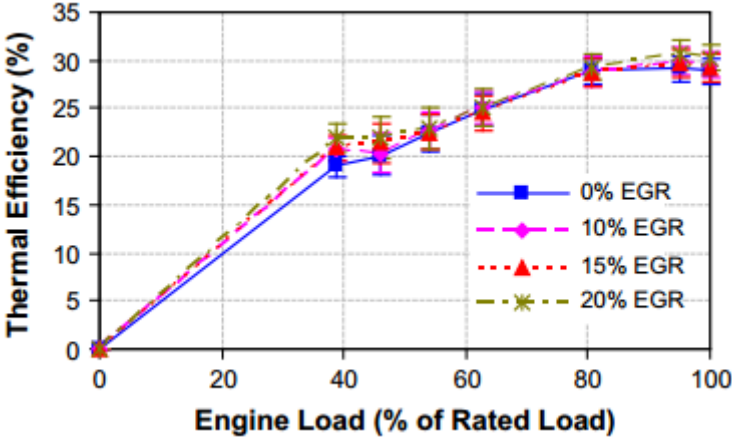


Figure2.11: Thermal efficiency for different EGR rates.

Brake Specific Fuel Consumption (BSFC) is lower at lower loads for engine operated with EGR compared to without EGR. However, at higher engine loads, BSFC with EGR is almost similar to that of without EGR. At higher loads, amount of fuel supplied to the cylinder is increased at higher rate and Oxygen available for combustion gets reduced. Thus, air fuel ratio is changed and this increases the BSFC as shown in figure2.12[1].

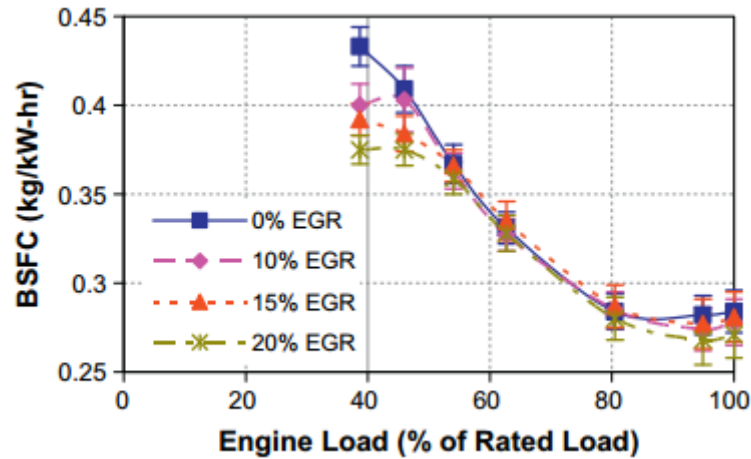


Figure2.12: Brake Specific Fuel Consumption for different EGR rates.

With increasing load, exhaust gas temperature also increases, when the engine is operated with partly-cooled EGR, the temperature of exhaust gas is generally lower than temperature of exhaust gas at normal operating condition. Exhaust gas temperature decreases with increase in EGR rate, The reasons for temperature reduction are relatively lower availability of Oxygen for combustion and higher specific heat of intake air mixture as shown in figure2.13.

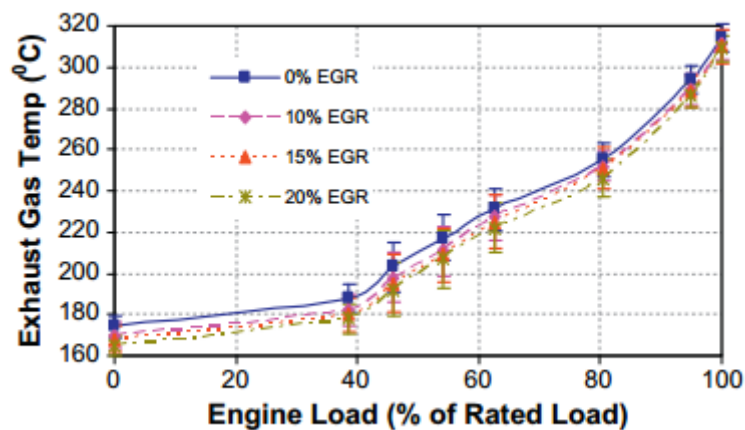


Figure2.13: Exhaust gas temperature for different EGR rates.

The degree of reduction in NO_x at higher loads is higher because of reduced Oxygen concentration and decreased flame temperatures in the combustible mixture. At the part load, O₂ is available in sufficient quantity but at high loads, O₂ reduces drastically, therefore NO_x is reduced more at higher loads as shown in Figure2.14[1].

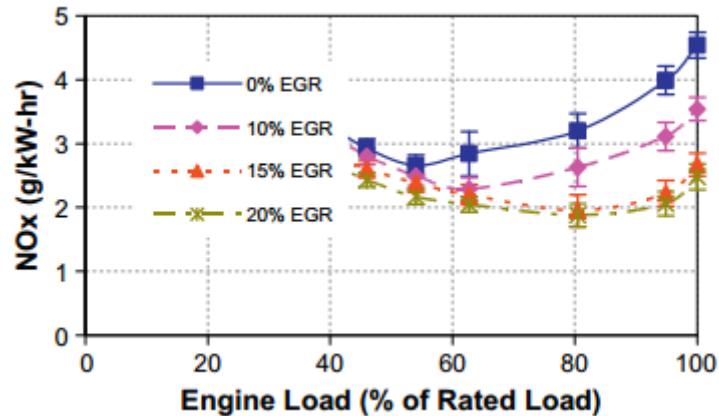


Figure 2.14: NOx for different EGR Rates.

2.5.1.3 Conclusions:

EGR is a very useful technique for reducing the NOx emission. In the present research, experimental investigations were conducted to study the effect of EGR on performance and emissions, EGR displaces Oxygen in the intake air by exhaust gas re-circulated to the combustion chamber. Exhaust gases lower the Oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. Reduced Oxygen and lower flame temperatures affect performance and emissions of diesel engine in different ways.

Thermal efficiency is slightly increased and BSFC is decreased at lower loads with EGR compared to without EGR. But at higher loads, thermal efficiency and BSFC are almost similar with EGR than without EGR. Exhaust gas temperature is decreased with EGR, NOx emission decreases significantly with increased EGR[1].

2.5.2 Maiboom A. [2008]:

The aim of this study is to distinguish and quantify some effects of EGR like the increase of intake temperature, the delay of Rate Of Heat Release (ROHR) and the decrease in Air Fuel Ratio on Combustion (AFR) and NO_x, Particulate Matter (PM) emissions on a typical modern automotive High-Speed Direct Injection (HSDI) engine at low and part load conditions under premixed and mixing-controlled combustion[6].

2.5.2.1 Experimental Apparatus and Procedure:

This study carried out the tests on a standard engine as shown in figure 2.15

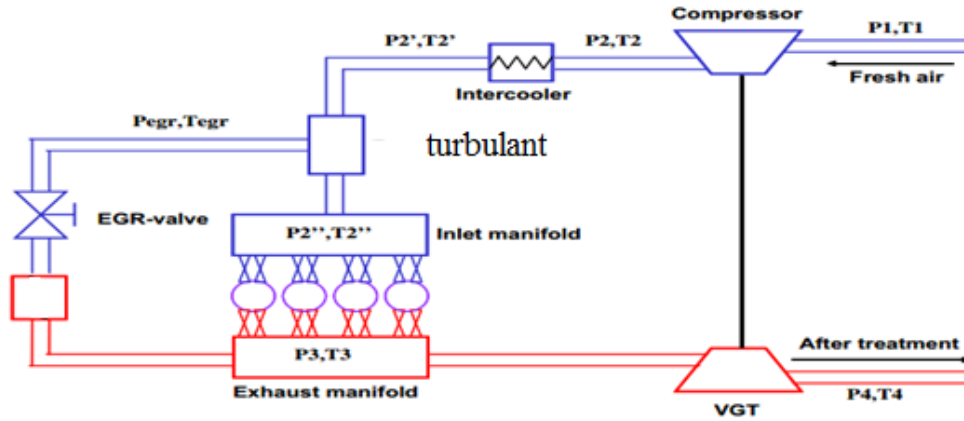


Figure 2.15: Engine configuration.

The study was conducted for various operating conditions at low load, A modified EGR circuit with an EGR mixer was used to ensure that air and re-circulated gases were perfectly mixed. The mixer was tested and permits to have less than 10% relative dispersion on EGR rate for the different cylinders.

The mean EGR rate is defined as follows:

$$X_{EGR} (\%) = 100 \cdot \frac{X_{CO_2_inlet}}{X_{CO_2_exhaust}}, \quad (\text{Eq 2.8})$$

Where:

$X_{CO_2_inlet}$ and $X_{CO_2_exhaust}$ are measured CO_2 concentrations in inlet and exhaust manifolds, respectively[6].

2.5.2.2 Influence of Inlet Temperature at Constant EGR Rate:

The first effect of EGR tested is the change in inlet temperature. Actually, when the EGR rate is increased, the inlet temperature after mixing with EGR increases, This increase in inlet temperature is accompanied by a reduction in in-cylinder trapped mass (thermal throttling effect), and thus in Oxygen quantity and heat capacity. To isolate the influence of inlet

temperature from the dilution effect due to EGR, the inlet temperature is varied separately by maintaining a constant EGR rate.

Influence of inlet temperature on NO_x and soot emissions:The corresponding influence on NO_x and soot emissions for 0% and 15.5% EGR is given in figure 2.16, 2.17, respectively. First of all, it can be noticed that for a given inlet temperature T₂'' NO_x emissions are higher and soot lower without pilot injection. Without pilot injection principal combustion is mainly premixed and the mean equivalence fuel–air ratio of the mixture formed during Ignition Delay (ID) must be too low for soot inception, explaining why soot emissions seem to be very low in the case of premixed combustions on the engine tested. The corresponding ROHR is higher, resulting in higher local temperatures, thus promoting NO_x formation. Furthermore, for a given inlet temperature T₂'', NO_x emissions are lower and soot emissions higher with 15.5% EGR compared to 0% EGR[6].

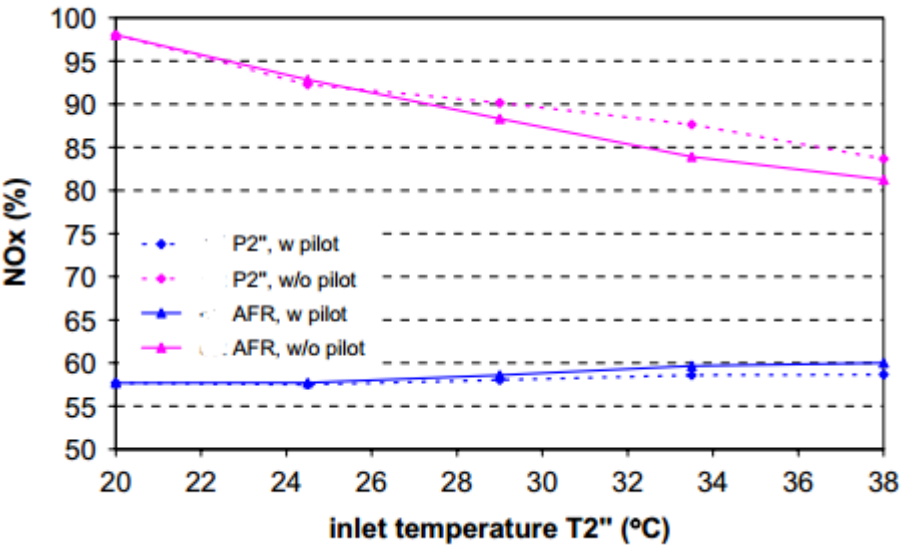


Figure 2.16: NO_x emissions for different inlet temperatures T₂''.

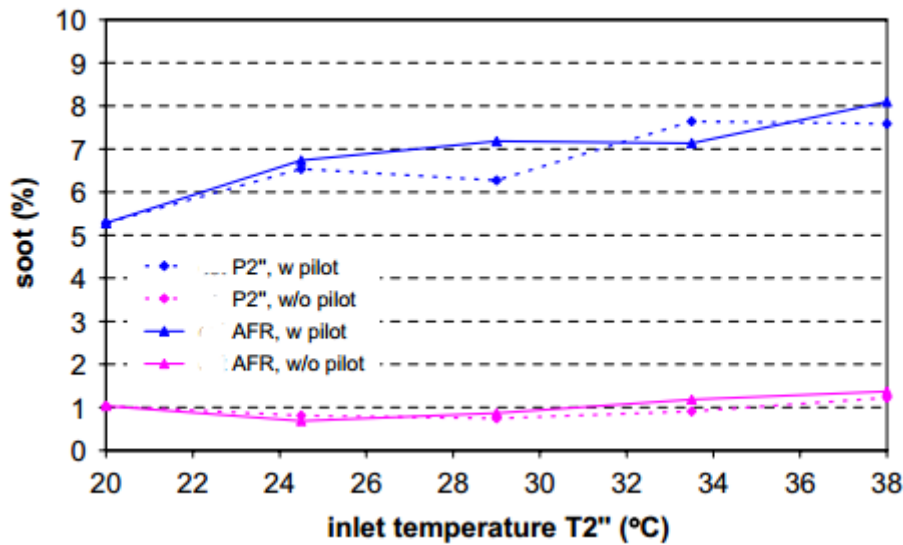


Figure 2.17: Soot emissions for different inlet temperatures T2''.

2.5.2.3 Influence of EGR at Constant Inlet Temperature:

In this study the influence of EGR on combustion, NO_x and soot emissions at constant inlet temperature:

Influence of EGR on NO_x and soot emissions: The influence of EGR on NO_x and soot emissions is given in figure 2.18, for a given EGR rate, NO_x emissions are higher and soot emissions lower without pilot injection as for the influence of inlet temperature. For a given EGR rate, soot emissions are higher at constant AFR, resulting in a bad NO_x/soot trade-off.

Furthermore, when trying to maintain a constant AFR, it was not possible to have EGR rates greater than 17% because the Variable Geometry Turbine (VGT) was not able to increase boost pressure to a higher value. Indeed, with a classical High-Pressure (HP) EGR loop, an increase of EGR rate leads irremediably to a decrease of gas flow through the turbine and thus to a decrease of boost pressure. As a consequence, trying to drastically reduce NO_x emissions without an important penalty on soot emissions by maintaining a suitable AFR is not achievable with the actual EGR configuration. Some modifications on the air loop could be made to obtain simultaneously high boost pressure and high EGR rates. With an HP EGR loop, the recirculated gases are taken after the turbine, thus the gas flow through the turbine, and consequently the boost pressure, are maintained when increasing EGR rate. It is thus easier to maintain a suitable AFR with a Low Pressure (LP) EGR loop [6].

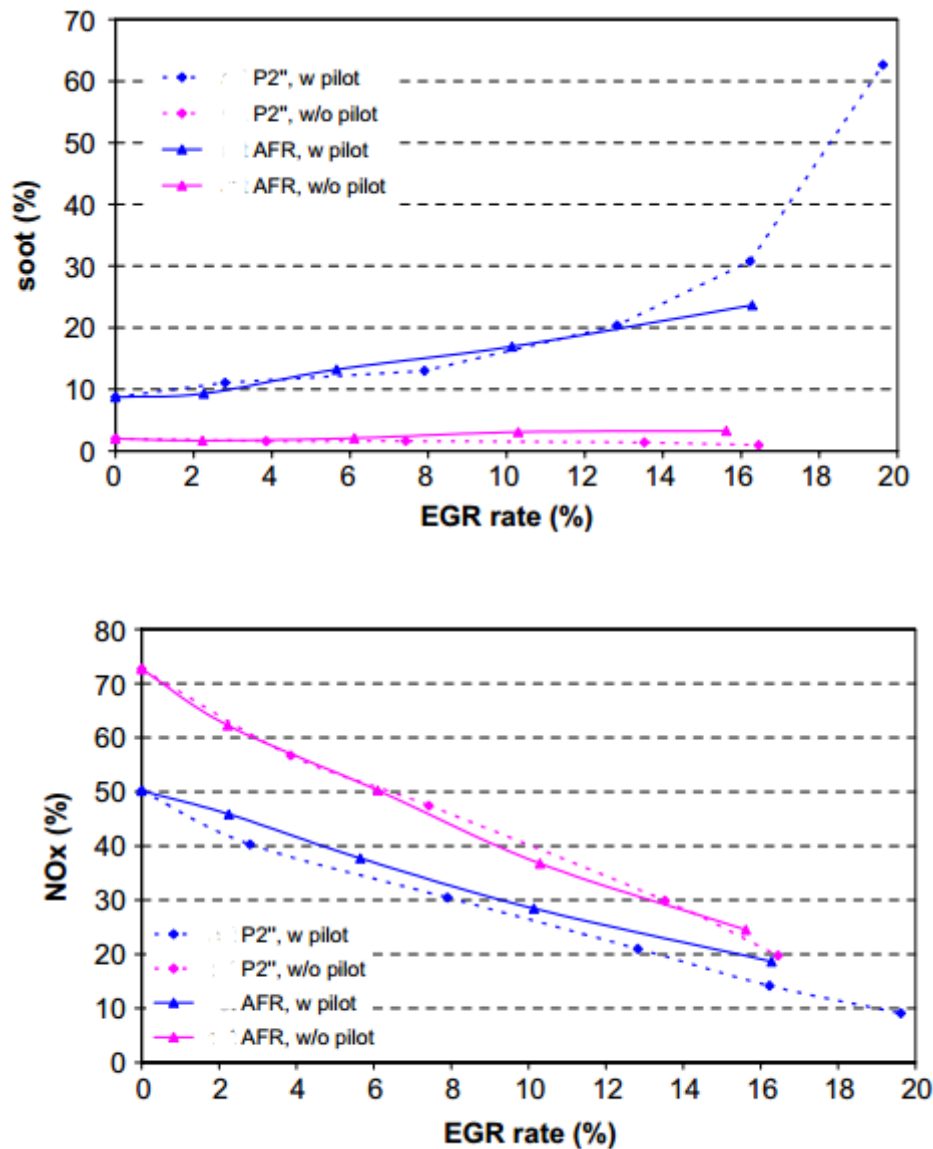


Figure 2.18: NO_x and soot emissions for different EGR rates.

2.5.2.4 Conclusions:

Some effects of EGR on combustion and NO_x–soot emissions were studied by various EGR strategies. Main conclusions are as follows:

A. The increase of inlet temperature at constant EGR rate has effects on combustion and emissions, that effects can be either positive or negative depending on operating conditions, for example, the reduction of NO_x emissions with increased inlet temperature.

B. At low-load conditions, very low- NO_x can be obtained with high EGR rates at constant boost pressure, because the combustion is delayed due to the high dilution. This is accompanied with an increase of BSFC (that can be higher than 10%).

C. For some operating conditions, EGR at constant AFR is a way to drastically reduce NO_x emissions without important penalty on BSFC and soot emissions[6].

2.5.3.1 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. As a result, one consequence of the dilution effect is the reduction of the local temperature 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.

2.5.3.2 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.

Chapter 3:proposed design

3.1 Introduction:

In our project we suggest to make double EGR in which a secondary EGR of short route is connected in parallel with the traditional EGR system, in addition, the turbulence of the EGR will be controlled manually. The secondary EGR is of mechanical type and manually operated valve, as shown in figure 3.1.

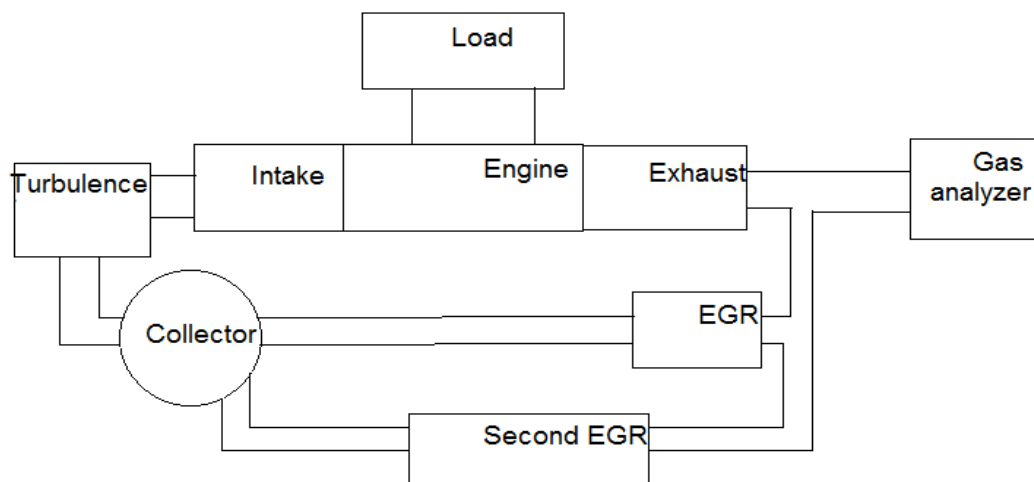


Figure 3.1: Proposed design.

3.2 Principle of System Work:

This system works by vacuum existing inside the intake manifold, this system consists of traditional EGR, also a Double EGR which contains of both, so the total EGR flow is the sum of the two. The exhaust gases quality will be compared between the traditional and the Double EGR system.

3.3 Test Bench:

We want to check the performance of the system, without the double EGR system(i.e. the traditional EGR) by recording the data (the percentage of NO_x & fuel consumption) at different engine loads(engine load will be generated using lamps), then taking data at different angles of turbulence at different engine loads, and we will repeat the experiment using secondary EGR at different load ,flow, turbulence and compare the data,and we want to use a gas analyzer to analyze the exhaust gases and take the result.

3.4 Engine layout modifications:

First, a line was taken from the exhaust line to return part of the exhaust gases into the intake manifold, then this line was connected with two valves of EGR (valve1 and valve2) in order to control the flow of exhaust gases that are returned to the engine,after that, a collector was placed to connect the two EGR valves and there is valve3 was added after the collector in order to make swirling to the recirculated gases to enter it into the intake manifold, as shown in the figure 3.2.



Figure 3.2: Engine layout modifications.

A volumetric flask was used to measure the fuel consumption for each experiment, and a protractor was used to control the angle of the valves (valve1, valve2 and valve3), a load was

added to the engine which was lamps connected to the alternator, four lamps were used in the experiment each lamp equal 60 watt and we use three cases (0 watt, 120 watt and 240 watt).

3.5 Components:

The project consists of the following parts:

- 1) Diesel engine 6 cylinder
- 2) Pipes
- 3) Three valves (ball valves)
- 4) Diesel fuel
- 5) Metal pieces
- 6) Gas analyzer
- 7) Load source (lamps)
- 8) Volumetric flask
- 9) Protractor

- 1) A pipe of the EGR system was taken and connected with main exhaust line by welding as shown in figure 3.3.

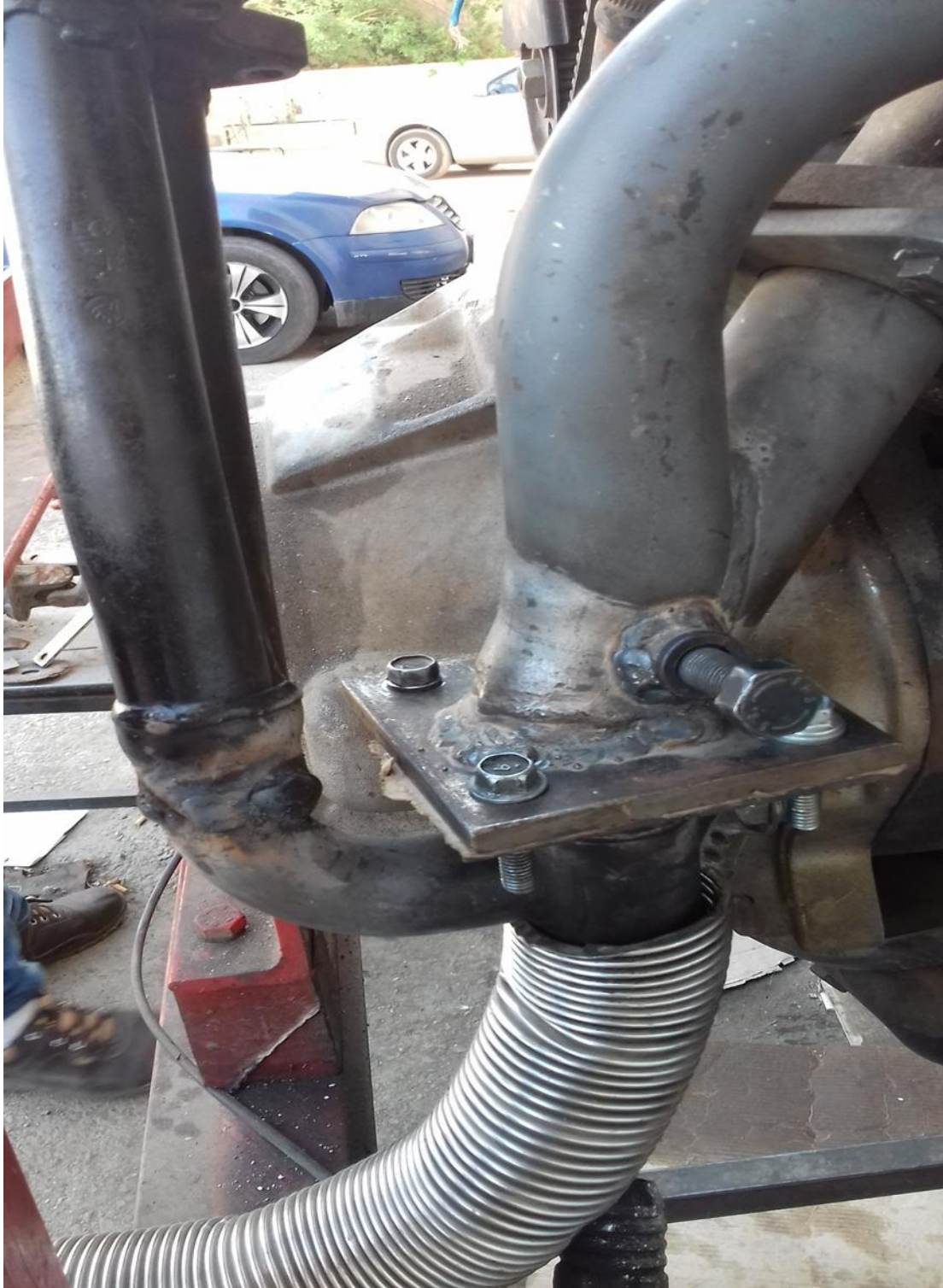


Figure 3.3: Back line of exhaust.

2) The line of EGR system that taken from main exhaust line divided into two lines, then connected with two EGR valves(valve1 & valve 2) by fitting, these valves control the flow of recirculated gases by control the angle of each valve manually, as shown in figure 3.4.

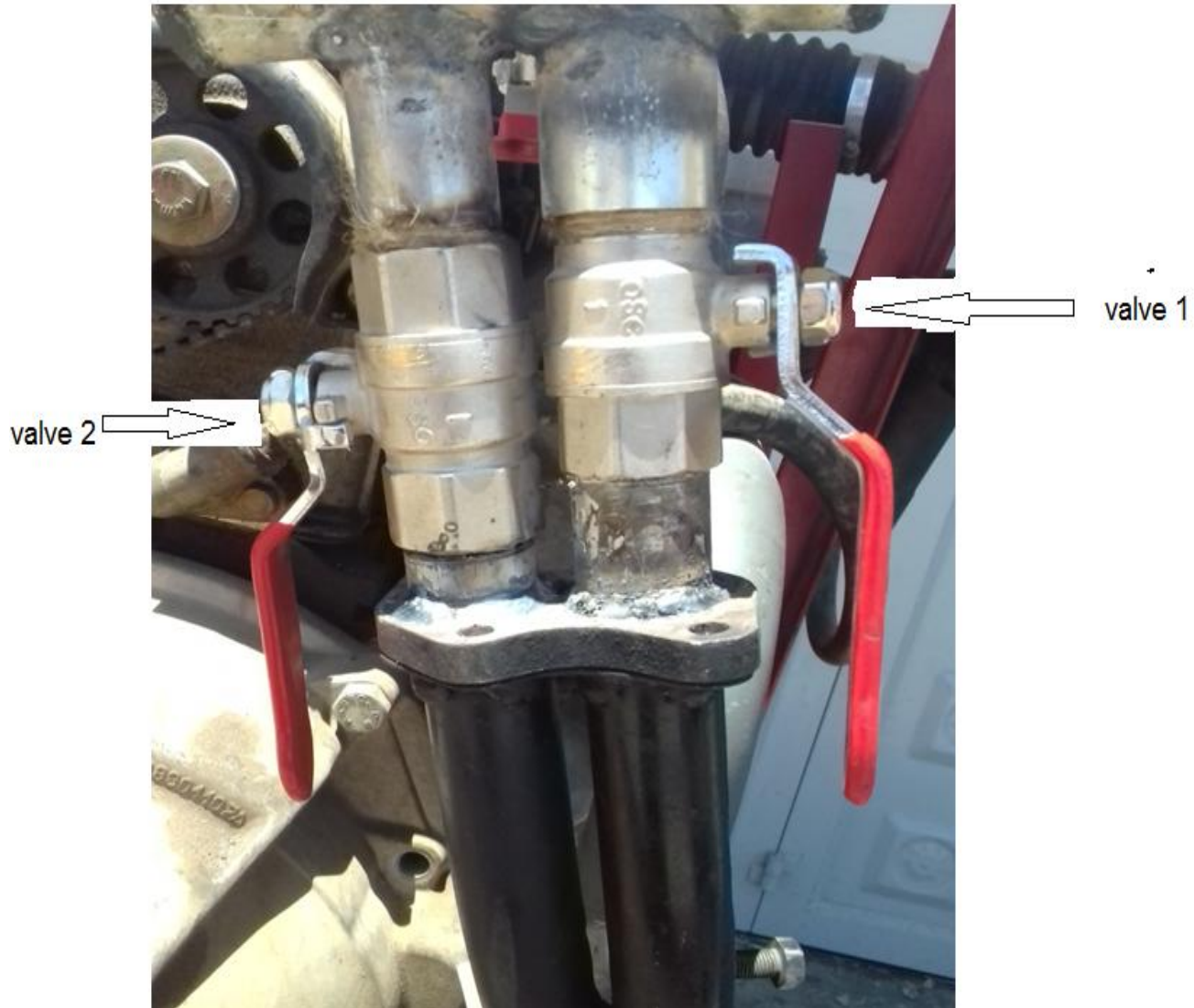


Figure 3.4: EGR valves.

3) Drill two holes in a collector and connect holes with two valves of EGR by welding as shown in figure 3.5.



Figure 3.5: EGR collector.

4) Drill another hole in the collector and Connect it with a pipe attached to a ball valve for turbulence and connect it to the intake manifold as shown in figure 3.6.



Figure 3.6: EGR turbulence.

5) Connect the load to the engine using the lamps, four lamps were used in the experiment each lamp equal 60 watt and we use three cases (0 watt, 120 watt and 240 watt), as shown in figure 3.7.



Figure 3.7: load on the engine.

6) connect the gas analyzer with the exhaust line in order to measure the NOx data and comparing result as shown in figure 3.8.



Figure 3.8: gas analyzer.

and the final project after assembling as shown in figure 3.9.



Figure 3.9: final project

Chapter 4: Experimental work

We have to run the engine as a first step, the experiment performed in four different modes as follows:

4.1 primary EGR without turbulence.

4.2 primary EGR with turbulence.

4.3 double EGR (primary and secondary) without turbulence.

4.4 Primary and secondary EGR with turbulence.

And all of these experiment modes done under load and without load condition.

4.1 primary EGR without turbulence:

at the beginning, the engine has been running and the primary EGR valve opened, the secondary EGR valve closed, the turbulence valve is fully open (no effect of turbulence) as shown in figure 4.1 and figure 4.2.



Figure 4.1: primary EGR without turbulence.

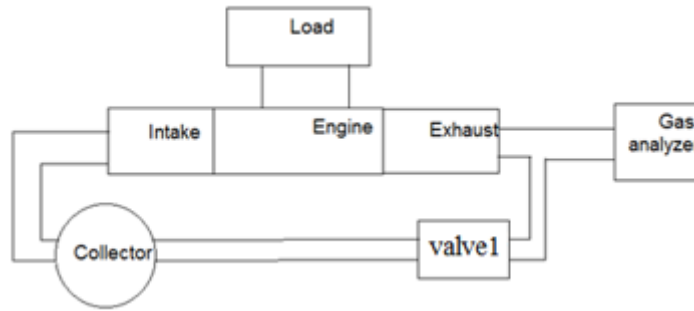


Figure4.2: block diagram for primary EGR without turbulence.

At different loads (0 watt, 120 watt and 240 watt), after connecting the gas analyzer device the data and the information result of the NO_x with the opening angles of valve1 (30 degree, 60 degree and 90 degree) as shown in figure 4.3, the fuel consumption as shown in figure 4.4.

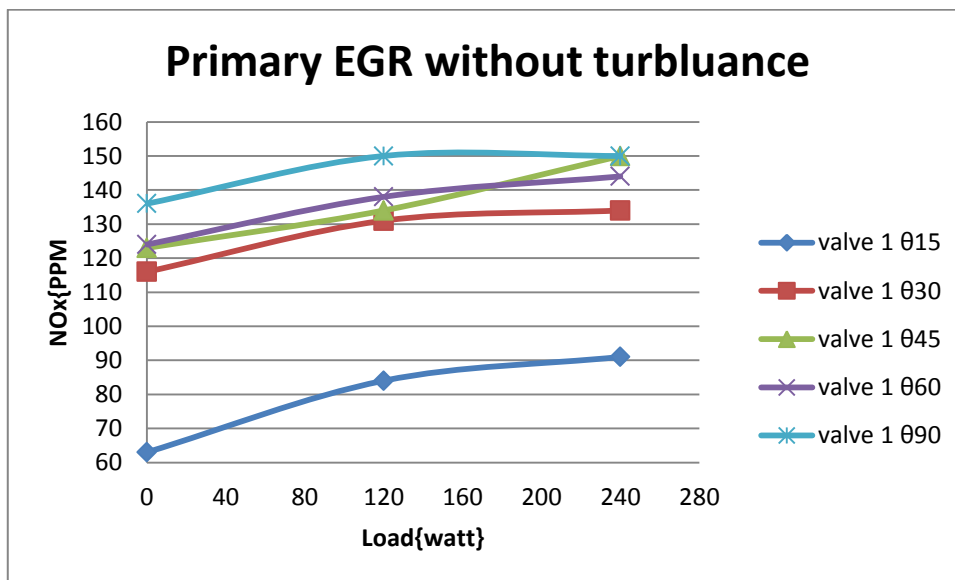


Figure 4.3: NO_x versus load at different angles of EGR valve without turbulence.

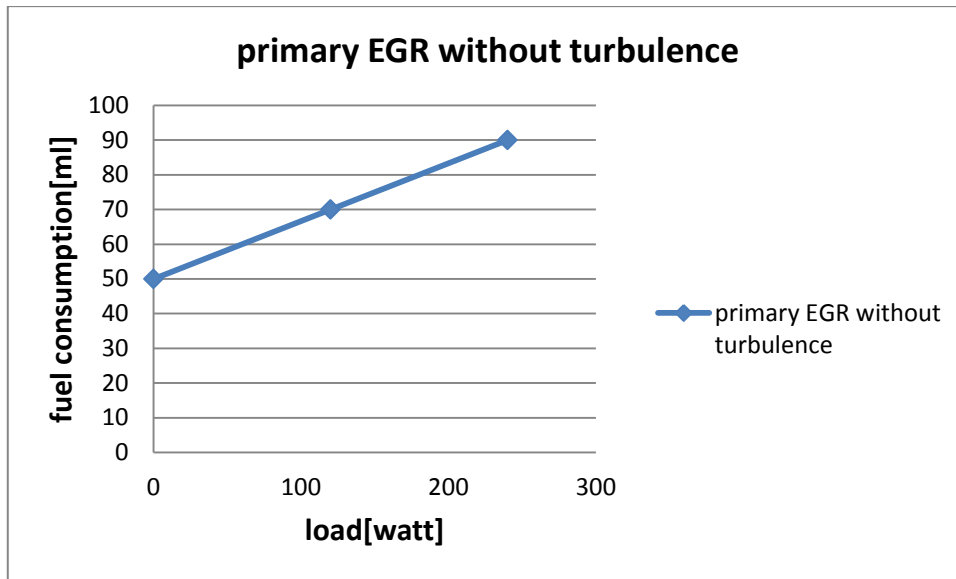


Figure 4.4: fuel consumption versus load with primary EGR without turbulence.

From the graphs, we noticed that the NO_x increases with increased the load, because the increase of temperature in the combustion chamber, that produce more NO_x . And the fuel consumption also increased because the increase of torque, in our experiment the perfect angle was 15 degree for valve1 because the recirculated gases less than the other angles.

4.2: the primary EGR with turbulence:

the primary EGR valve opened and increasing the opening angle of the turbulence valve gradually as shown in figure 4.5 and figure 4.6.



Figure 4.5: the primary EGR with turbulence.

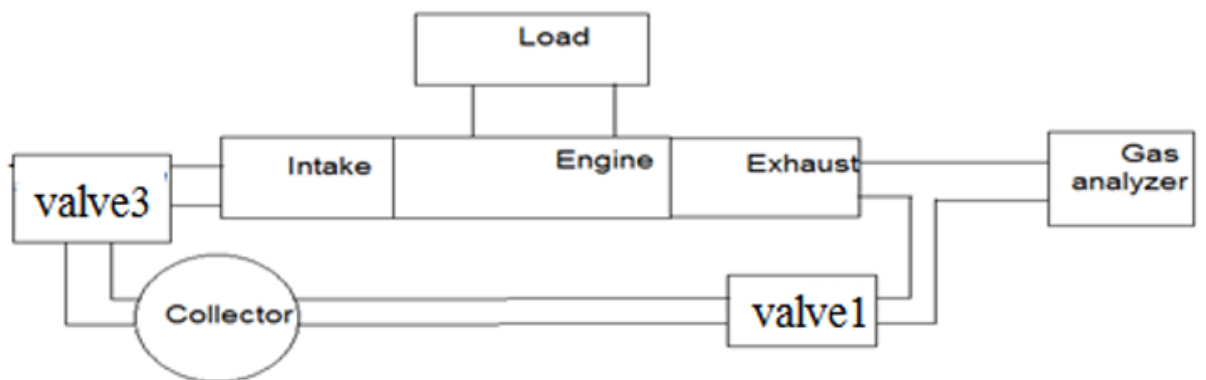
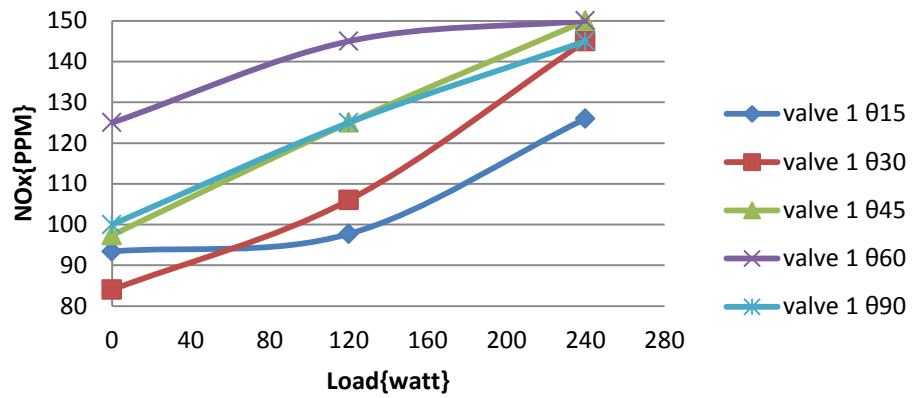


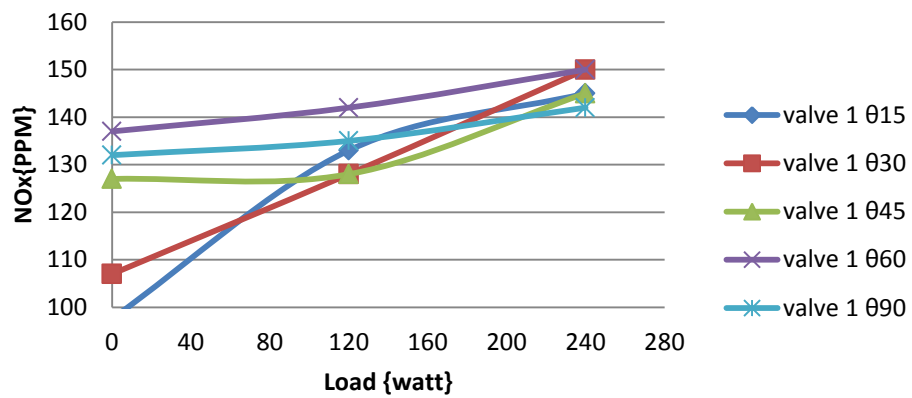
Figure 4.6: block diagram for the primary EGR with turbulence.

At different loads (0 watt, 120 watt and 240 watt), after connecting the gas analyzer device the data and the information result of the NO_x with the opening angles of valve1 (30 degree, 60 degree and 90 degree) as shown in figure 4.7, the fuel consumption as shown in figure 4.8.

a) primary EGR with turbulance valve3 θ15



b) primary EGR with turbulance valve3 θ30



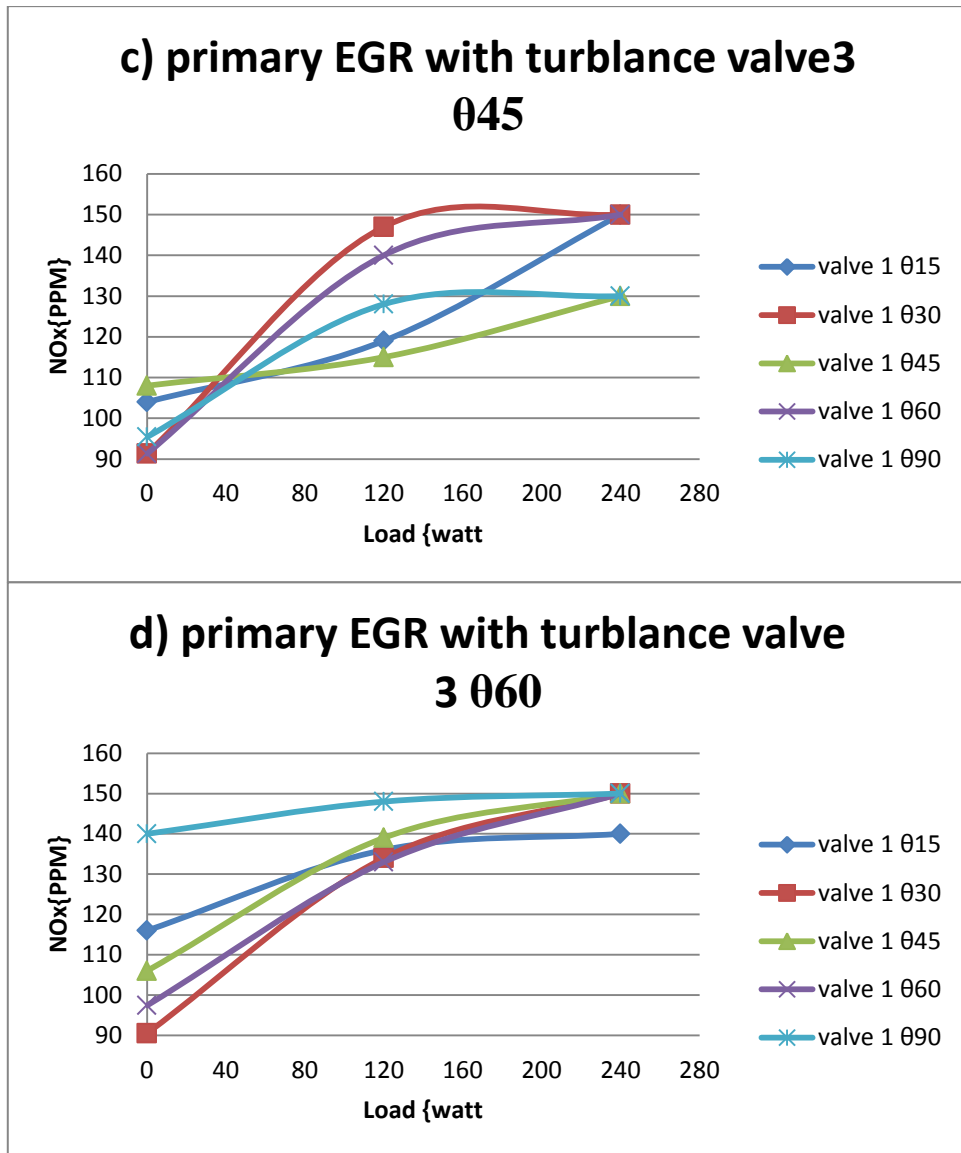


Figure 4.7: NOx versus load at different angles of EGR valve with turbulence.

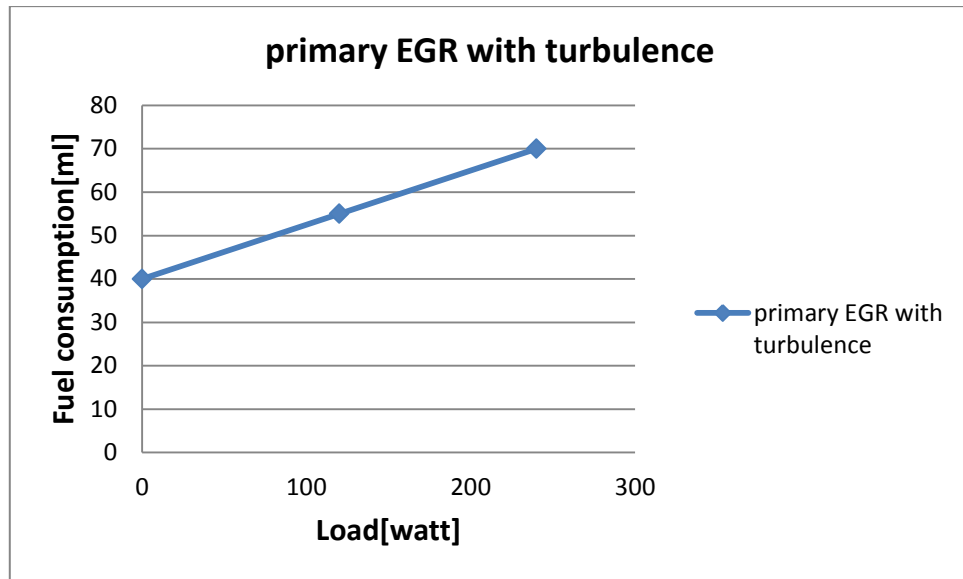


Figure4.8: fuel consumption versus load with primary EGR with turbulence.

From the graphs, we noticed that the NO_x increases with increased the load, because the increase of temperature in the combustion chamber, that produce more NO_x. And the fuel consumption also increased because the increase of torque, in our experiment the perfect angle was 15 degree for valve3 because the recirculated gases have the best turbulence angle and the recirculated gases less than the other angles and get best result.

4.3 Double EGR (primary and secondary) without turbulence:

the two valves of the double EGR have been opened and the flow of the exhaust gas divided into the two valves, the turbulence valve is fully open (no effect of turbulence) as shown in figure 4.9 and figure 4.10.



Figure 4.9: double EGR (primary and secondary) without turbulence.

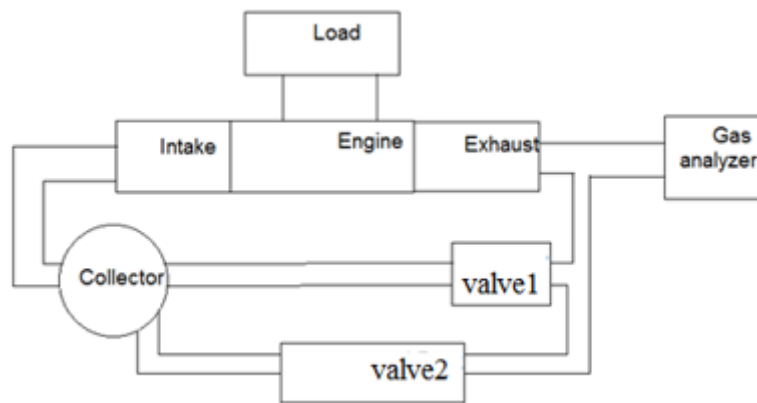


Figure4.10: block diagram for double EGRwithout turbulence.

At different loads (0 watt, 120 watt and 240 watt), after connecting the gas analyzer device the data and the information result of the NO_x with the opening angles of valve1 (30 degree, 60 degree and 90 degree)as shown in figure 4.11, the fuel consumption as shown in figure4.12.

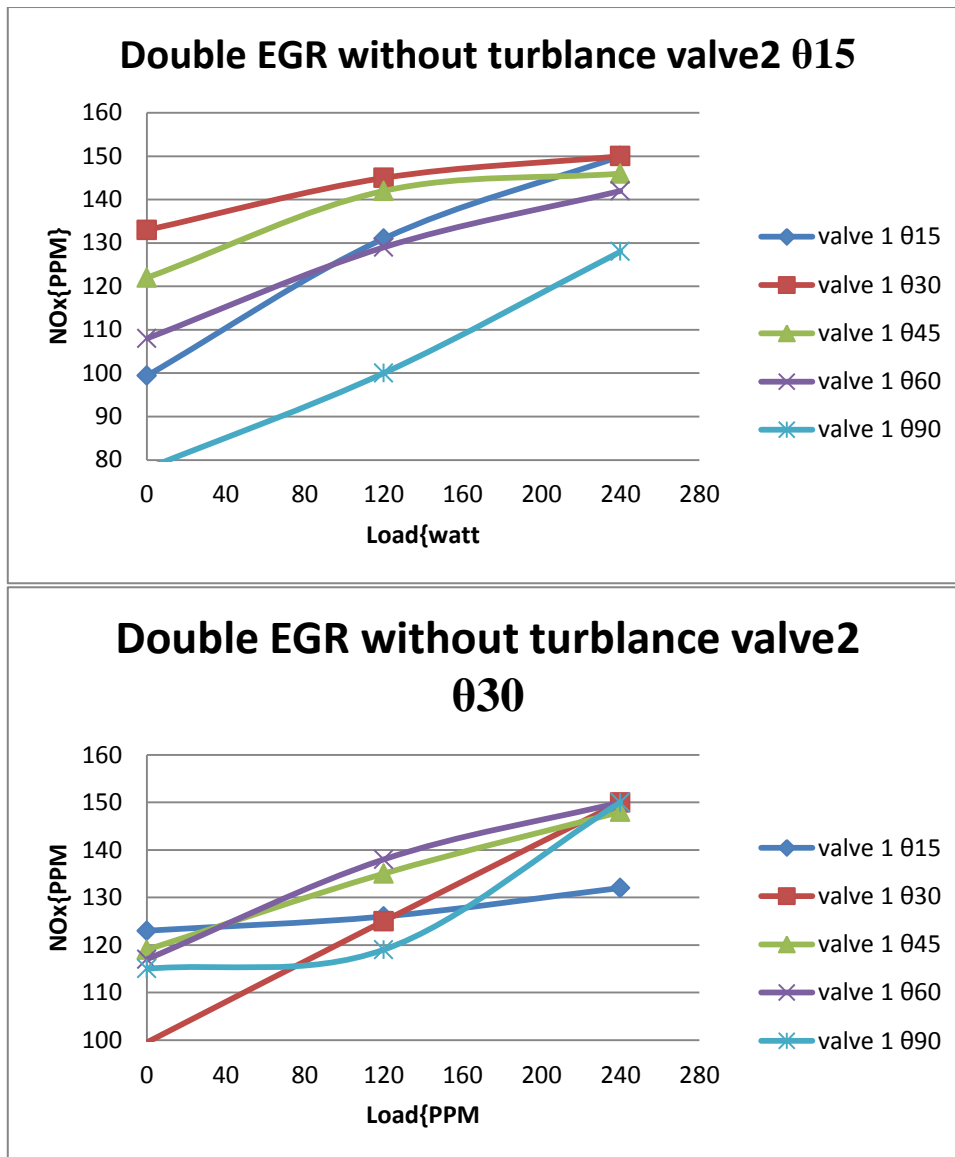


Figure 4.11: NOx versus load at different angles of double EGR valves without turbulence.

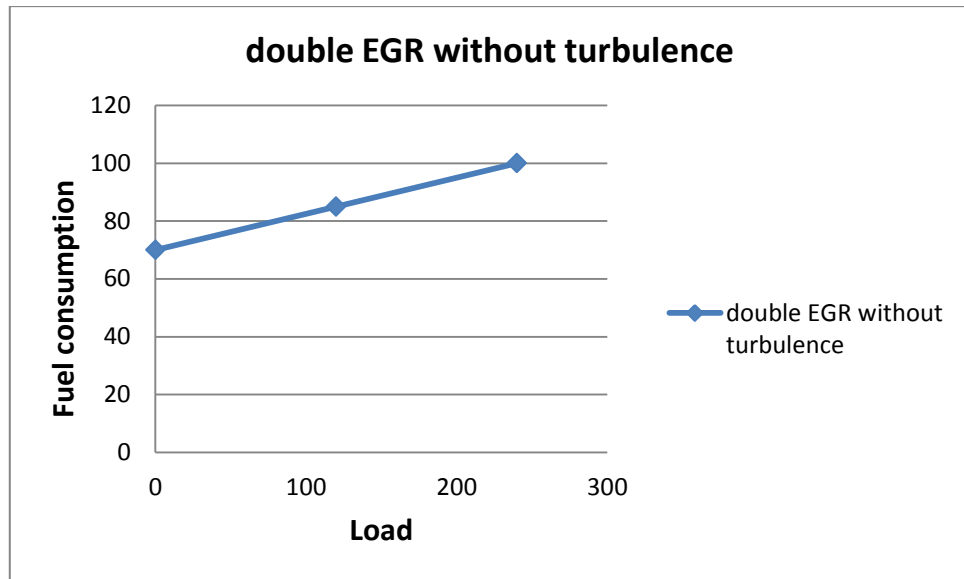


Figure 4.12: fuel consumption versus load with double EGR without turbulence.

From the graphs, we noticed that the NO_x increases with increase the load, because the increase of temperature in the combustion chamber, that produce more NO_x . And the fuel consumption also increased because the increase of torque, in our experiment the perfect angle was 30 degree for valve2 because the amount of recirculated gases increased.

4.4 Double EGR (primary and secondary) with turbulence :

The two valves of the double EGR have been opened and the flow of the exhaust gas divided into the two valves , and increasing the opening angle of the turbulence valve gradually as shown in figure 4.13. and figure 4.14.



Figure 4.13: double EGR (primary and secondary) with turbulence.

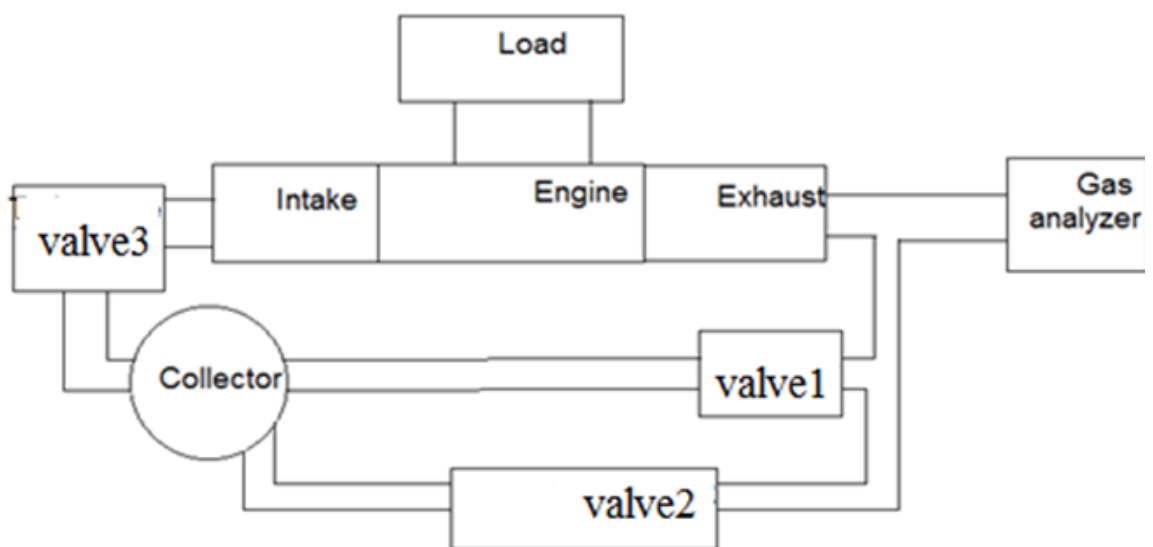
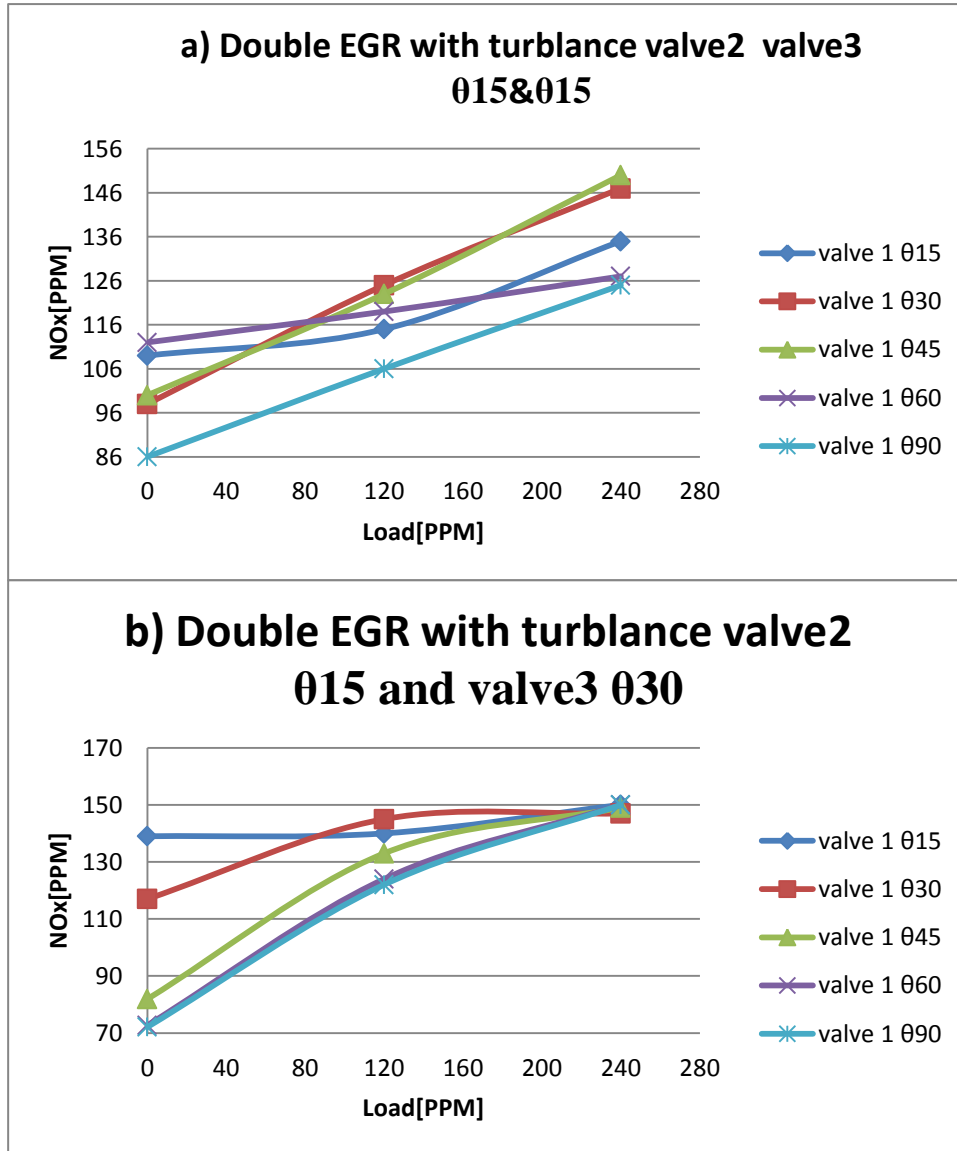
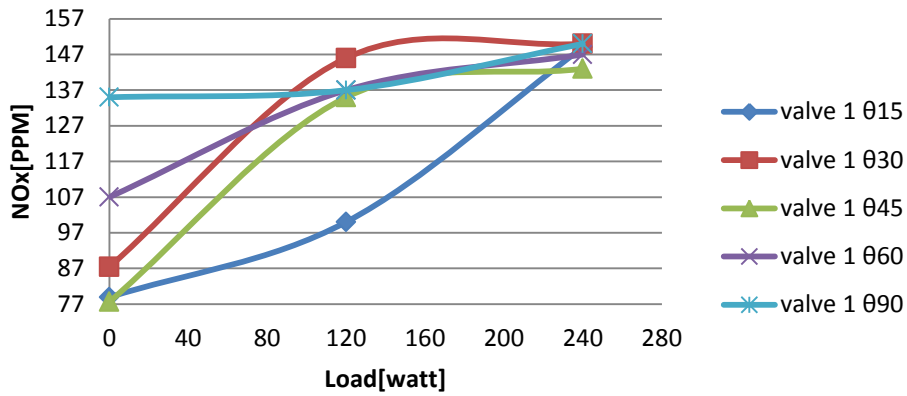


Figure 4.14: block diagram for double EGR with turbulence.

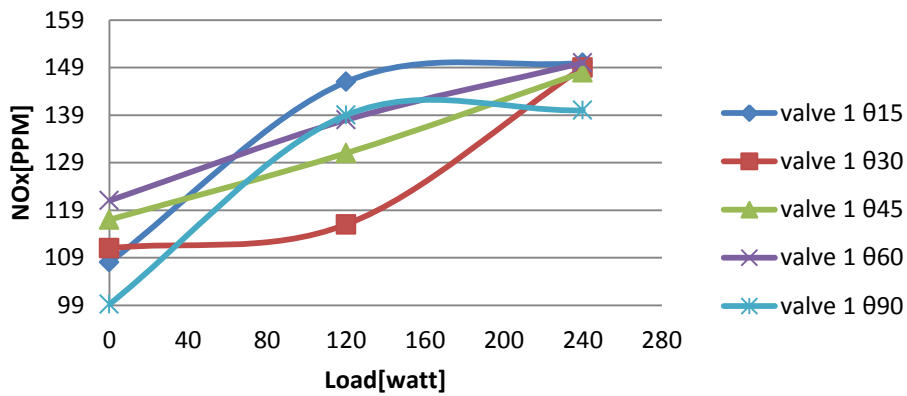
At different loads(0 watt, 120 watt and 240 watt), after connecting the gas analyzer device the data and the information result of the NO_xwith the opening angles of valve1 (30 degree, 60 degree and 90 degree)as shown in e figure 4.15, the fuel consumption as shown in figure 4.16.



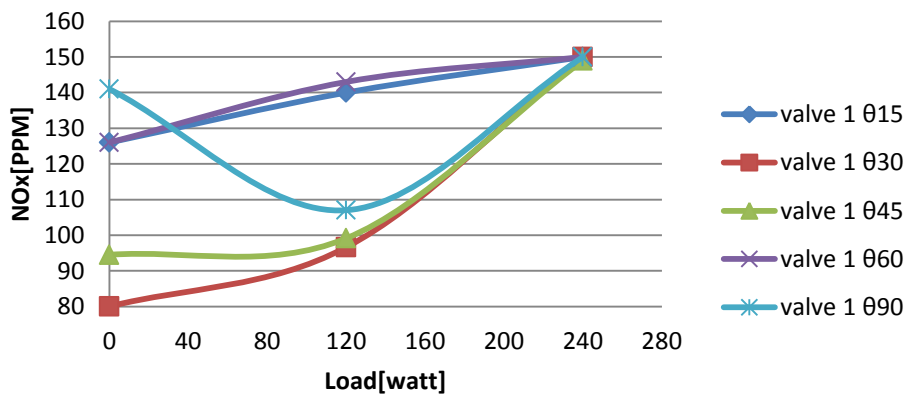
c) Double EGR with turbulance valve2 015 and valve3 045



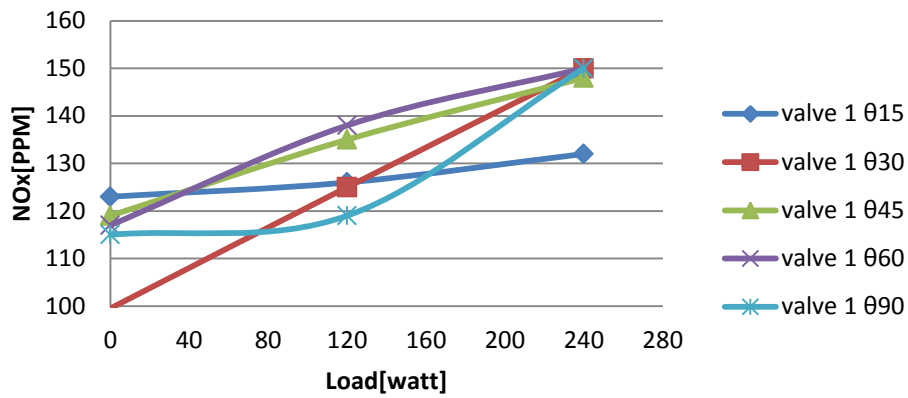
d) Double EGR with turbulance valve2 015 and valve3 060



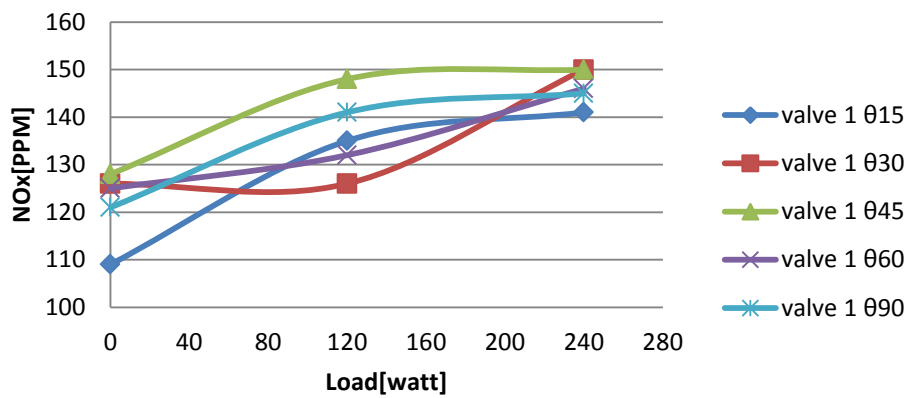
e) Double EGR with turbulance valve2 015 and valve3 090



f) Double EGR with turbulence valve2 030



g) Double EGR with turbulence valve2 030 and valve3 015



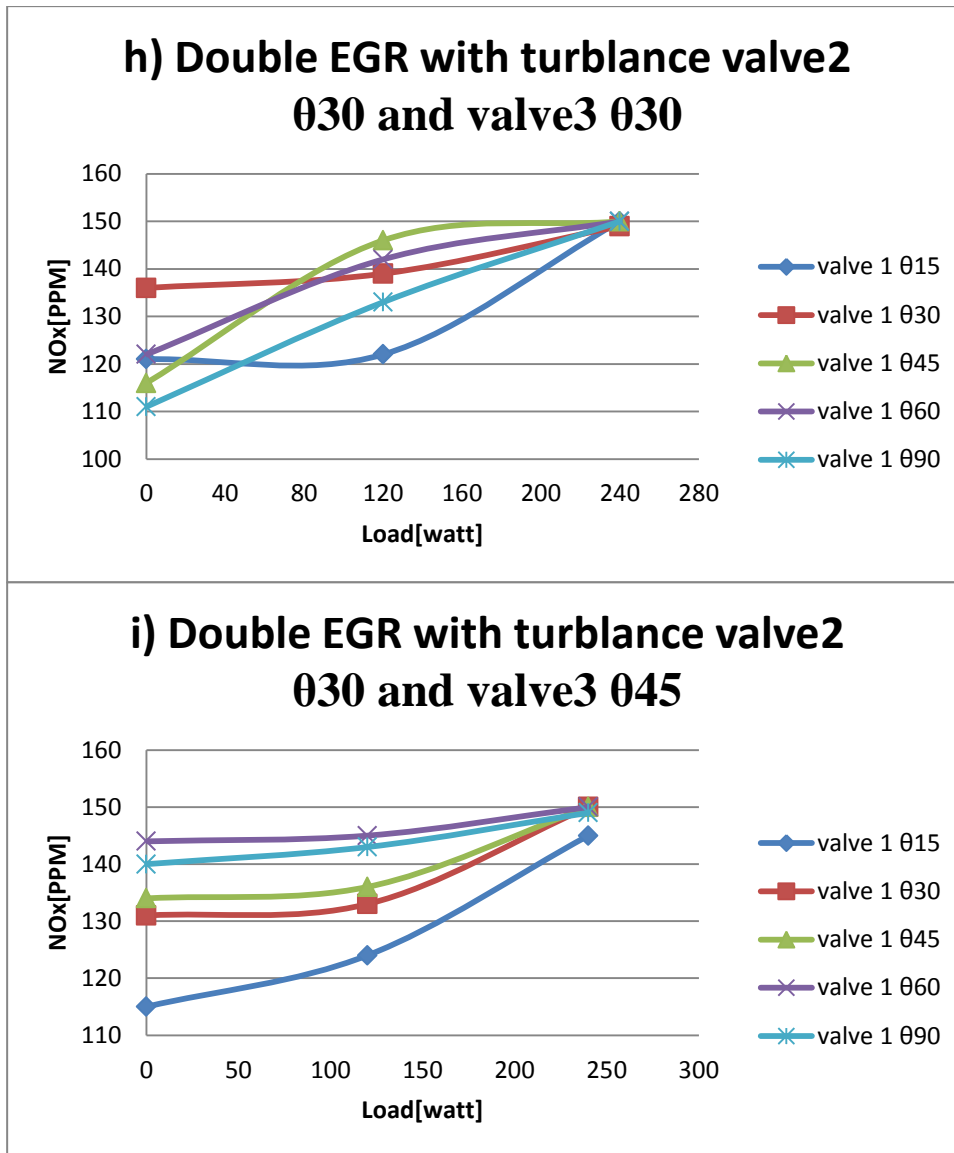


Figure 4.15: NOx versus load at different angles of double EGR valves with turbulence.

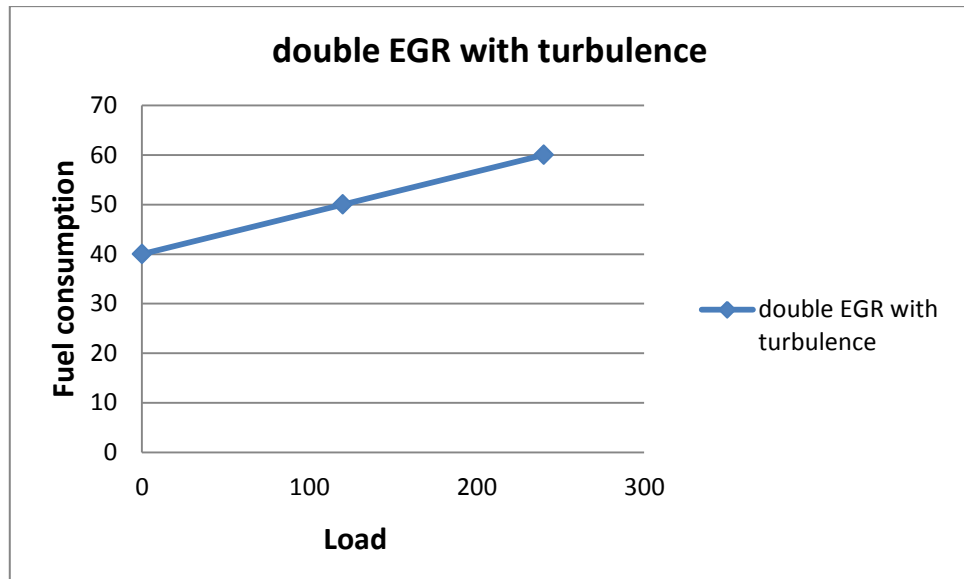


Figure 4.16: fuel consumption versus load with double EGR with turbulence.

From the graphs, we noticed that the NO_x increases with increased the load, because the increase of temperature in the combustion chamber, that produce more NO_x . And the fuel consumption also increased because the increase of torque, in our experiment the perfect angle was 15 degree for valve2 and 45 degree for valve3 because the amount of recirculated gases increased andthe recirculated gases have the best turbulence angle.

Chapter 5: Conclusion and recommendation:

5.1: conclusion:

After the project experiments, it was found that there was a noticeable variation in the readings as the NO_x ratio in the exhaust gases was reduced by the use of a double EGR without turbulence by approximately 57.7%.

Also, we observe from the readings that the best angle of flow of exhaust gases is the angle of 30 degree for the primary EGR without turbulence and the best reading obtained when the two EGR valves with turbulence were opened at the angle of 30 degree and the percentage is almost 42.4% for double EGR with turbulence.

Note that the fuel consumption has been reduced by using a primary EGR without Turbulence compared with the double EGR without Turbulence by almost 21.4%, and the percentage of the fuel consumption also decreased when used primary EGR with turbulence compared with Double EGR with turbulence approximately 10%.

5.2: Recommendations:

- 1) Using flow meter, can control the flow of EGR and have a good result.
- 2) Using an electric EGR, may be have a good result for fuel consumption and NO_x decrease better than mechanical one.
- 3) Using turbo and connect it with EGR to produce double turbo with double EGR.

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