College of Engineering

Exhaust Gas Recirculation(EGR)Cooling System

By :

Mahdi Irjan Ali Shraha

Ahmad Khamayseh

Supervisor :

Dr. ZuhdiSalhab

Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor degree in automotive engineering

Hebron , May 2018

Dedication

إلى السنبلة الذهبيّة في بلادي و بيّارات البرتقال ...إلى كروم الـ عنَب و غصن الزيتون ...و دَم الشهداء و دَمعة الأطفال .

إلى رغيف الطابون و ريح الـ زعتر ......إلى (فلسطين). تِلك التي صنعتني كي أكو نُ هنا.

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

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

الى ملاكي في الحياة...الى معنى الحب و الى معنى الحنان و التفاني....الى بسمة الحياة و سر الوجود...

الى من كان دعائها سر نجاحي و حنانها بلسم جراحي الى اغلى الحبايب...(امي الحبيبة).

الى من كلله الله بالهيبة و الوقار....الى من علمني العطاء بدون انتظار....الى من احمل اسمه بكل افتخار..ارجو 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 الى الابد...(والدي العزيز)

إلى من تحلو بالإخاء وتميزوا بالوفاء والعطاء إلى ينابيع الصدق الصافي......(أصدقائي).

إلى الذين أجدهم معي في السراء والضراء ..... (أقاربي الأعزاء.)

إلى من سرنا سوياً ونحن نشق الطريق معاَ نحو النجاح والإبداع إلى... (زميلاتي وزملائي).

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

Acknowledgment:

أشكر الله العلي القدير الذي أنعم علينا بنعمة العقل والدين والقائل في محكم تنزيله "و فوق كل ذي علم عليم" . سورة يوسف آية . ٦٧

وقال رسول الله صلى الله عليه وسلم : " من وضع إليكم معروفا فكافئوه , فإن لم تجدوا ما تكافئونه به فادعوا له حتى تروا أنكمكافأتموه " ..رواه ابو داوود.

أنني بكامل شكري وامتناني ووفاءا وتقديرا واعترافا مني بالجميل أتقدم بجزيل الشكر لأولائك المخلصين الذينلم يألوا جهدا في مساعدتنا في مجال هذا البحث العلمي ، و أخص بالذكر الاساتذة الأفاضل (م. محمد سليمالقواسمة ،م. خالدسدر ،م. عبد الرحمن الشرباتي) فشكرا جزيلا لكم.

وصاحب الفضل الأكبر في توجيهي ومساعدتي في تجميع المادة البحثية الدكتور القدير " زهدي سلهب " لك مناكل الاحترام والتقدير والشكر اللامتناهي على هذا الجهد في تشجيعنا على القيام بهذا العمل وتوفير المعلوماتوالنصائح القيمة .شكرا لهذا الدعم والتواصل الطيب ، الذي له تأثير كبير على الشعور بأهمية ما نعمل عليه.

والشكر الخاص للطالب "محمد النجار" على دعمه ومساندته لنا.

وأخيرا ، أتقدم بجزيل شكري إلى كل من مدوا يد العون والمساعدة في اخراج هذه الدراسة على أكمل وجه.

Abstract :

In internal combustion engines, the engine temperature increases due to frequent combustion within the combustion chamber, due to the interaction of Oxygen atoms to the formation of Nitrogen Oxides, which have a negative effect on humans, plants and the ozone layer, especially when sulfur oxides interact to form acid rain. Therefore, car companies have introduced a technique to reduce these emissions through an exhaust gas recirculation.

The exhaust gas recirculation system takes (15-30) % of exhaust gases after cooling and re-entering the combustion chamber to reduce the engine temperature and reduce nitrogen oxides. In the present study, Cool by water line will be added to the exhaust gas recirculation system to reduce the amount of oxides Nitrogen compared to conventional system.

The exhaust gas recirculation system will be controlled separately; the cooler will be designed with a new specification for this system.

في محركات الاحتراق الداخلي، تزداد درجة حرارة المحرك بسبب الاحتراق المتكرر داخل غرفة الاحتراق,وذلك بسبب تفاعل ذرات الأكسجين لتشكيل أكاسيد النيتروجين، والتي لها تأثير سلبي على البشر والنباتات وطبقةالأوزون، وخصوصا عندما تتفاعل أكاسيد الكبريت لتشكيل الأمطار الحمضية. ولذلك، أدخلت شركات السياراتتقنية للحد من هذه الانبعاثات من خلال نظام إعادة تدوير الغاز العادم.

نظام إعادة تدوير غاز العادم يأخذ (15-30) %من غازات العادم بعد التبريد وإعادة دخول غرفة الاحتراق للحدمن درجة حرارة المحرك والحد من أكاسيد النيتروجين. في هذه الدراسة, سيتم إضافة خط تبريد عن طريقالماء إلى نظام إعادة تدوير غاز العادم للحد من كمية أكاسيد النيتروجين مقارنة مع النظام التقليدي.

سيتم التحكم في نظام إعادة تدوير غاز العادم بشكل منفصل, وسيتم تصميم المبرد بمواصفات جديدة لهذا النظام

List of Content

List of Figure

List of Table

Chapter 1:

Introduction

1.1 Importance of the Study:

In diesel engines increase the temperature of the combustion chamber produced by repeated combustion processes, thus incomplete combustion will occur due to repeatedcombustion, thus nitrogen oxides (NO_X) will be produced, which have a negative impact on the environment.

The techniques commonly used to reduce nitrogen oxides (NO_X) are the recirculationof exhaust gases, water injection and combustion optimization.

The common technique used is therecirculationof exhaust gases in which (15-30)% of the exhaust gas is recycled into the intake manifold.

The EGR system introduces exhaust gases into the combustion chamber in the form of an inert gas that absorbs heat resulting from combustion, which reduces the temperature of the combustion chamber and thus reduces the ratio of nitrogen oxides.

1.2 Study Objectives:

In this project, we know the effect of EGR cooling on nitrogen. This will be done by adding a cooler with high-level cooling properties and the oxides will be tested empirically.

The following items identify the aim of this study:

- Develop on EGR traditional with experimental procedures and compare results.
- Comparison the performance of the engine with and without EGR cooler and variance percentage.

1.3 Motivation of Study:

Nitrogen oxides have negative effects on plants, humans and the environment in general. Nitrogen oxides affect plant growth and also negatively affect the human respiratory tract and some people may be sensitive, and also negatively affect the environment where nitrogen oxides react with sulfur dioxide to produce harmful acid rain , Thus reducing the level of NOx becomes an important issue in combustion engines.

1.4 Expected Budget:

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

equipment's	Cost ($)
stainless steel pipes	60$
Battery	50 $
Pipe fittings	20$
Volumetric flaks	5$
Pump diesel	130$
Thermocouple sensor	20$
Belt timing	20$
Elbows andPipes	47$
Connectors and Valves	25$
Engine Paint and EGR	17$
Full diesel	30$
Total	424 $

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																
literature review																
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 of motor																
Bringing tools																
System work & connect with motor																
Writing report																
Make presentation																

Table 1.3: Time Table for the second semester.

Chapter 2: State of the Art

2.1Introduction Exhaust Gas Recirculation (EGR):

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].

2.2 Combustion of a Hydrocarbon Fuel:

Stoichiometric combustion of simple hydrocarbon in Oxygen forms Carbon Dioxide (CO_2) from all of the Carbon and water (H_2O) the hydrogen, generally, the chemical equation for stoichiometric combustion of a hydrocarbon in oxygen is:

$$C_xH_y + zO_2 \rightarrow xCO_2 + \frac{y}{2}H_2O \qquad (2.1)$$

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:

$$C_xH_y + z(O_2 + 3.76N_2) \rightarrow xCO_2 + \frac{y}{2}H_2O + z\,3.76\,N_2 \quad (2.2)$$

Where z = x + ¼y [1].

The incomplete (partial) combustion of a hydrocarbon with Oxygen produces a gas mixture containing mainly CO_2, CO, H_2O and H_2 . The general reaction equation for incomplete .combustion of one mole of a hydrocarbon in oxygen is:

$$C_zH_y + zO_2 \rightarrow aCO_2 + b\,CO + c\,H_2O + d\,H_2 \quad (2.3)$$

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 (C_3H_8) with four moles of O_2 , 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

$$C_XH_Y + a\ O_2 + 3.76N_2 \ \rightarrow bCO_2 + dH_2O\ g\ + fO_2 + zCO + a\,3.76N_2 \quad (2.4)$$

NO_X means the sum of NO and NO_2 contents in flue gas recalculated on NO_2.

$$NO_X = NO + NO_2 \quad (2.5)$$

The "liberated" O atoms can react with N_2through a relatively slow reaction:

$$O + N_2 \rightarrow NO + N \quad (2.6)$$

The N atoms "liberated" in this reaction quickly react with O_2 :

$$N + O_2 \rightarrow NO + O \quad (2.7)$$

Also given NO.

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.

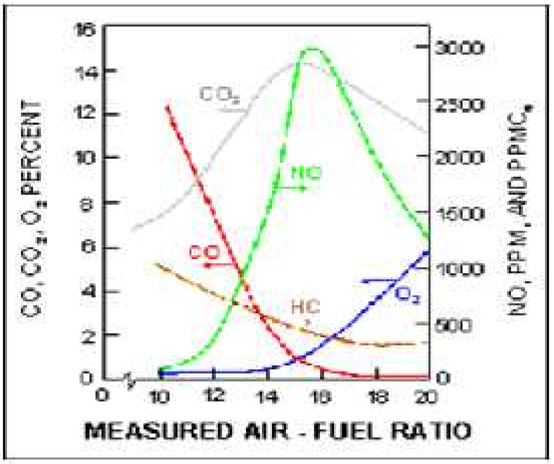


Figure 2.1: Exhaust gases as a function of AFR [2].

The combustion of internal combustion engines results in nitrogen oxides that affect the environment and humans, hence the idea of EGR , which reduces the emission of toxic gases and reduces the temperature.

2.3EGR Principle of Operation:

The exhaust gas recycling valve rotates part of the exhaust gases back into the combustion chamber of the engines shown in figure 2.2. This process reduces pollution from the vehicle and also:

Reducing the heat of the combustion chamber by reducing the compression ratio of the engine by adding exhaust gases to the combustion chamber where the gases are inert, ineffective and non-flammable, the EGR inserts them into the combustion chamber and the temperature is less than the heat of the combustion chamber. As these gases do not burn and the temperature is less than the temperature of the combustion chamber, with heat absorption and reduction,

.

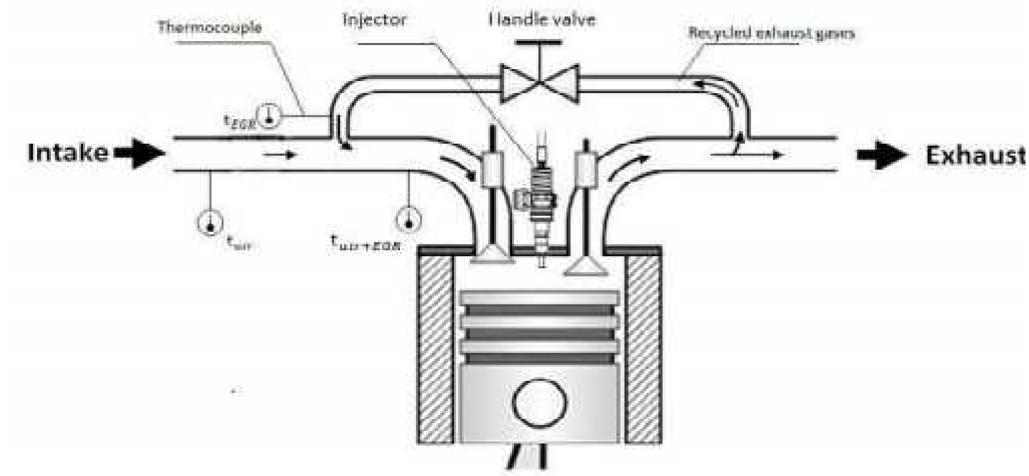


Figure 2.2: EGR Principle of Operation without cooler [2].

2.4 EGR cooler Principle of Operation:

The application of hot EGR simultaneously increases inlet charge temperature and decreases inlet charge mass of an engine. The resulting reduction of inlet charge mass and oxygen is commonly referred to as thermal throttling.

This phenomenon is increased in systems where the EGR system is present, which leads to a deterioration in the performance of the engine. This phenomenon can be solved by the EGR cooler, whether thermally or chemical.

The EGR cooler system works to increase the air intake to the combustion chamber and thus addresses the phenomenon ofthermal throttling and instability in the engine and can solve all the problems found in the standard EGR system by the EGR cooler.

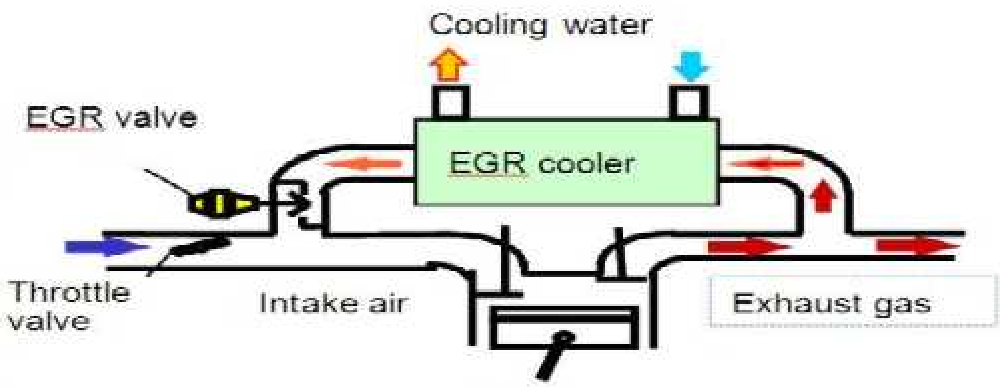


Figure 2.3: EGR cooler Principle of Operation with cooler [3].

2.5.1 Effects of EGR rate on NOX:

"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 NO_x formation [4]. The decrease in NO_x 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 (CO_2) and water vapor (H_2O) compared with oxygen (O_2) and hydrogen (H_2) at constant pressure resulting in lower gas temperature during combustion process, and particularly in a lower flame temperature"[4].

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 .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". [4].

c) The chemical effect:

"The recalculated H_2O and CO_2 are dissociated during combustion, modifying the combustion process and the NOx formation. In particular, the endothermic dissociation of H_2O results in a decrease of the flame temperature "[4].

d) An increase of the ignition delay

"With EGR rate is generally observed, so that the premixed part of combustion is higher, without EGR, it may increase NOx emissions, but in the presence of EGR, the rate of heat release premixed peak is lower, so that it would reduce NOx emissions" [4].

2.5.2 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 2.5.1 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 [5].

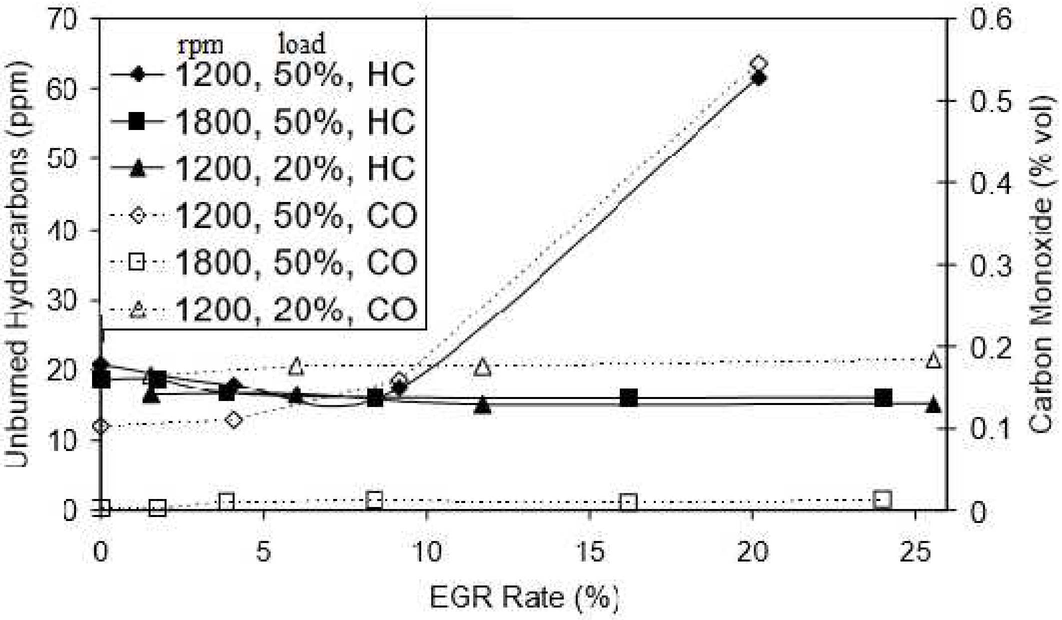


Figure 2.4: The effect of EGR rate on HC and CO [5].

2.6 Disadvantages and Difficulties of EGR:

Since EGR reduces the available oxygen in the cylinder, the production of particulates (fuel which has only partially combusted) is increased when EGR is applied. This has traditionally been a problem with diesel engines, where the trade-off between NO_x and particulates is a familiar one to calibrators.

The deliberate reduction of the oxygen available in the cylinder will reduce the peak power available from the engine. For this reason the EGR is usually shut off when full power is demanded, so the EGR approach to controlling NO_x fails in this situation.

The EGR valve cannot respond instantly to changes in demand, and the exhaust gas takes time to flow around the EGR circuit. This makes the calibration of transient EGR behavior particularly complex- traditionally the EGR valve has been closed during transients and then re-opened once steady state is achieved. However, the spike in NOx / particulate associated with poor EGR control makes transient EGR behavior of interest.

The recalculated gas is normally introduced into the intake system before the intakes divide in a multi-cylinder engine. Despite this, perfect mixing of the gas is impossible to achieve at all engine speeds / loads and particularly during transient operation. For example poor EGR distribution cylinder-to-cylinder may result in one cylinder receiving too much EGR, causing high particulate emissions, while another cylinder receives too little, resulting in high NO_x emissions from that cylinder.

Although the term EGR usually refers to deliberate, *external* EGR, there is also a level of *internal* EGR. This occurs because the residual combustion gas remaining in the cylinder at the end of the exhaust stroke is mixed with the incoming charge. There is therefore a proportion of *internal* EGR which must be taken into account when planning EGR strategies. The scavenging efficiency will vary with engine load, and in an engine fitted with variable valve timing a further parameter must be considered.

2.7 The advantages with cooler:

The reduction of future diesel engine NOx emission limits forces the heavy and light duty diesel engine manufactures to develop system to comply more stringent legislation. Today the most effective method to do that is through the use of cold

Exhaust Gas Recirculation (EGR) in order to reduce the peak temperature in the combustion chamber, and where the EGR cooler plays a very important role. The reduction in allowable emissions within the new legislation, forces the increase of EGR rates, requiring EGR coolers with a higher thermal dissipation capacity. This increase in thermal efficiency needs also to be done without compromising other requirements in the design of the EGR cooler, such as the cooler size, the pressure drop in the gas circuit, the fouling behavior and, of course, costs.

The systems are primarily liquid cooled systems, with one of the coolant loops passing through the EGR cooler.

EGR coolers are primarily stainless steel. A major reason for that is that for the environment where the cooler is located, other metals would rust, and rust flakes can result in major damage to the engine. EGR coolers vary in size based on specific engine requirements, including the amount of flow that will pass through the EGR, the cooling required, and the space limitations in the area.

2.8 Literature Review

2.8.1 NageshMavinahally et al (1996) have investigated theoretically the benefits of the Miller cycle diesel engine with and without low heat rejection on thermodynamic efficiency, break power and fuel consumption. It further illustrates the effectiveness of thin thermal barrier coatings to improve the performance of military and commercial IC engines. Miller cycle was accomplished by closing the intake valve late and the engine components were coated with for low heat rejection. A significant improvement in brake power and thermal efficiency were observed [6].

2.8.2 HansruediStebler et al (1996) have measured and compared the emissions and performance parameters of a medium size, medium speed DI diesel engine with increased charge air pressure and reduced but fixed inlet valve opening period to the standard engine. The application of the Miller system with fixed inlet valve timing showed a significant reduction of nitric oxide emissions at improved efficiency over a broad range of operating conditions. NOx emissions in the high load range were reduced by 15 - 20% in comparison to the conventional engine. At the same time, fuel consumption decreased by 0.5 – 2%. Results of simulations for both performance

parameters and NOx emissions were in good agreement with the experimental findings[6].

2.8.3 In a study conducted by Tomazic et al., the impacts of cooled and uncooled EGR on engine performance were highlighted. The results of the investigation showed that use of cooled EGR has a lesser negative impact on brake specific fuel consumption (bsfc) and smoke emissions. Similar results were observed in studies by Ladommatos et al. The effects of hot and cooled EGR on NOx production were also compared in a study by Zheng et al. where the application of enhanced cooled EGR was achieved, resulting in reduced exhaust NOx.[6]

2.8.4 Abd-Alla (2002) has reviewed the potential of exhaust gas recirculation (EGR) to reduce the exhaust emissions, particularly NOx emissions, and to delimit the application range of this technique. In this work a detailed analysis of previous and current results of the EGR effects on the emissions and performance of diesel engines were introduced. The authors have concluded that adding EGR to the air flow rate to the Diesel engine, rather than displacing some of the inlet air, appears to be a more beneficial way of utilizing EGR in diesel engines.[6]

2.9.1 The effect of pollutant on environment:

The main constituents of deposits in diesel EGR coolers are particulate matter, hydrocarbons, and acids. The primary composition of PM in non-premixed internal combustion engines is soot [7,8,9]. Soot represents the elemental carbon portion of the total particulate matter and consists of small roughly spherical particles (20-30 nm), which tend to agglomerate on cooler wall surfaces. The hydrocarbon based particulates, also referred to as soluble organic compounds make up the remaining portion of total PM. According to literature, the soluble organic fraction is a measure of HC and sulfate in the exhaust stream which condenses onto the surface of the soot particles after the gases have been mixed, diluted and cooled with air. Since the temperatures of EGR gases are relatively high, the SOF of total PM is small in comparison to elemental carbonaceous soot [8,9].

Hydrocarbons will condense on the EGR cooler surface when the temperature is below the dew point for the partial pressure of the compound, and so the heavier, highly concentrated species will condense most. This concept was illustrated in a study conducted by Hoard et al. where the extractable fraction of the HC deposits was measured and the results indicated that the heavier chain hydrocarbons and aromatics constitute the majority of hydrocarbon condensate species

Organic acids such as formic and acetic acid are present in diesel exhaust, but are not of great concern with respect to cooler fouling. More important is the condensation of sulfuric and nitric acids onto the EGR cooler walls. The dew point for nitric acid is approximately 40°C which is slightly below normal operating temperatures of diesel EGR coolers. Sulfuric acid, on the other hand has a dew point of roughly 100°C which is near the EGR cooler temperature range. In a study conducted by Girard et al. liquid condensate was removed from an EGR cooler system at a rate of 20-24 ml/hr with a cooler outlet temperature of 103°C. Up to 1.3% of the condensate collected was sulfuric acid

2.9.2 Deposit Removal Mechanisms:

The following summary of suggested removal mechanisms was presented by Hoard et al:

- Blow Out: Accumulated deposits might „blow off the surface at high flow conditions due to the shear force induced by the high gas flow.
- Flaking: Water, liquid HC, and/or acids reduce the strength of deposit adhesion causing the deposits to flake off of the surface.

- Cracking: Deposits may harden over time and eventually crack due to thermal or other stresses, causing portions to break away from the surface.
- Evaporation/Oxidation: The portion of deposits which are semi-volatile may evaporate off of the surface if the temperatures are high enough. Similarly oxidation of soot particulates may occur with sufficient temperatures. However, oxidation of soot is unlikely in EGR coolers as the required oxidation temperature is above 500°C.
- Wash Out: Condensation of water, HC, and/or acids may form a liquid film that would carry deposits out of the cooler.

Although the aforementioned removal mechanisms have been reported in several studies [8,9,10], there is a lack of experimental data that clarifies these mechanisms or conditions under which they occur.

After that, from 2010 till now, the purpose of using EGR system was expanded to exceed the goal of NO_x reduction but also for fuel economy.

2.10 History of EGR System:

In fact, the using of EGR system is ancient and backs to the middle of 20^{th} century specifically in 1972/1973. From that time until 1980_s it was used to control the NO_xin gasoline fueled passenger car and light-duty truck engines in North America. After that and in the beginning of 1990_s, the EGR system was introduced to diesel passenger cars and light-duty trucks and then heavy-duty diesel engines. The cooled EGR became very used and common in the beginnings of 2000_s especially for heavy duty diesel engines. [11].

Chapter 3: System Design

Heat Exchangers

3.1 Introduction:

Heat exchangers are devices used to transfer heat between two or more fluid streams at different temperatures. Heat exchangers find widespread use in power generation, chemical processing, electronics cooling, air-conditioning, refrigeration, and automotive applications. In this chapter, will be examine various aspects of heat exchanger design and analysis.

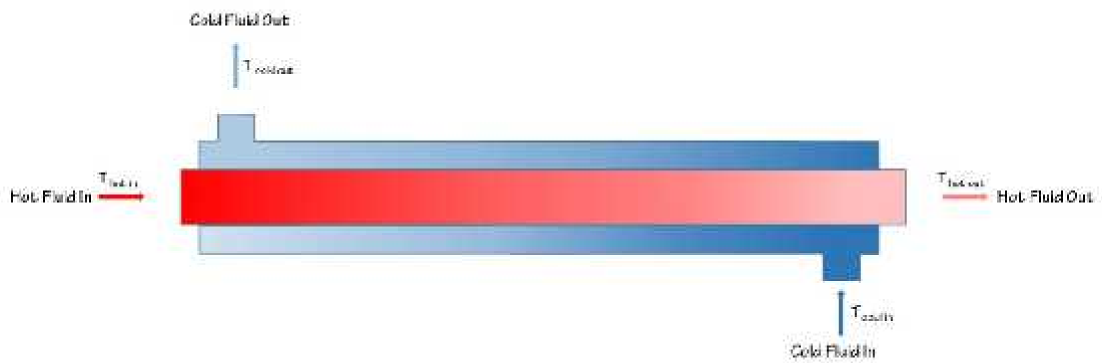


Figure 3.1: Proposed design "The heat exchanger" [1٢].

3.2 Heat Exchanger Classification:

Due to the large number of heat exchanger configurations, a classification system was devised based upon the basic operation, construction, heat transfer, and flow arrangements.

* Transferprocesses: direct contact or indirect contact

*Geometry of construction: tubes, plates, and surfaces

*Heat transfer mechanisms: single phase or two phase flow

*Flow Arrangement: parallel flow, counter flow, or cross flow.

3.3 Heat Exchanger Design Methods:

The goal of heat exchanger design is to relate the inlet and outlet temperatures, the overall heat transfer coefficient, and the geometry of the heat exchanger, to the rate of heat transfer between the gases &fluid . That is, the design of a two fluid heat exchanger used for the purposes of recovering waste heat. Will be begin first, by discussing the basic principles of heat transfer for a heat exchanger [12]

3.3.1 LMTD Method:

The log mean temperature difference (LMTD) is derived in all basic heat transfer[12].

Text sit may be written for a parallel flow or counter flow arrangement. The LMTD has the form:

$$\Delta T_{LMTD} = \Delta T_2 - \Delta T_1 \div \ln \Delta T_2 \ / \Delta T_1 \quad (3.6)$$

Where ΔT_1 and ΔT_2 represent the temperature difference at each end of the heat exchanger, whether parallel flow or counter flow. The LMTD expression assumes that heatexchanger [12].

Once calculated, the LMTD is usually applied to calculate the heat transfer in an exchanger according to the simple equation:

$$Q = U * A * LMTD \quad (3.7)$$

Where Q = Heat Transfer.

U = Heat Transfer coefficient.

3.3.2 NTU Method:

The effectiveness / number of transfer units (NTU) method was developed to simplify a number of heat exchanger design problems. The heat exchanger effectiveness is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate if there were infinite surface area. The heat exchanger effectiveness depends upon whether the hot fluid or cold fluid is a minimum fluid. That is the fluid which has the smaller capacity coefficient $C = \dot{m} C_p$. If the cold fluid is the minimum fluid then the effectiveness is defined as[12]:

$$\varepsilon = C_{max} (T_{H,in} - T_{H,out}) / C_{MIN} (T_{H,in} - T_{C,in}) \qquad (3.8)$$

We may now define the heat tansfer rate as:

$Q = \varepsilon C_{min}(T_{H,in} - T_{C,in})$ (3.9)

It is now possible to develop expressions which relate the heat exchanger effectiveness to another parameter referred to as the number of transfer units (NTU). The value of NTU is defined as:

$$NTU = UA / C_{min} \quad (3.10)$$

3.4 Heat Exchanger Design Fundamentals:

3.4.1 Thermal Design:

Thermal design of heat exchangers, in its entirety, is governed by the following important relationships[12].

- Enthalpy rate equations

$q = qh = qc = \dot{m}\,\Delta$(3.11)Where:

q= heat transfer rate for the hot (h) and cold (c) fluids

$\dot{m}$= fluid mass flowrate

Δh change in enthalpy

- Heat transfer rate equation

$q = UA\Delta T_m$ (3.12)

Where:

U overall heat transfer coefficient

A heat transfer surface area

ΔT_m log mean temperature difference

For single-phase fluids in a heat exchanger, the enthalpy rate of change is $\Delta h = c_p \Delta T$, where c_p is the specific heat of the fluid at constant pressure.

$$\dot{m}_c C_{p,c}(T_{c,out} - T_{c,in}) = \dot{m}_h C_{p,h}(T_{h,in} - T_{h,out}) \quad (3.13)$$

The effectiveness of a heat exchanger is defined as the fraction of actual heat transferred to the maximum possible heat transferrable.

$$\varepsilon = q_{actual} / q_{max} \quad (3.14)$$

For EGR coolers, the maximum heat transfer possible is determined as:

$$q_{max} = \dot{m}_h C_{p,h} (T_{h,in} - T_{h,out}) \quad (3.15)$$

3.5 EGR Cooler design :

The diameter of the UNICOIL iron pipe is 5.5 cm and the outer diameter is 6cm. A copper pipe with an inner diameter of 2.5 cm and 3 cm outside, which is inside the iron pipe UNICOIL, two pieces of iron are brought in cylindrical shape. It also brought two pieces of iron in the form of a rectangular length of 10 cm and a thickness of 4 mm and were collected as a cover for iron pipe UNICOIL

Figure 3.2: Design of cooling water pipe.

3.5.1 processing the cooling catch :

will be cut Pipe a length of 35 cm and a diameter of 6 cm galvanianese steel type to protect from staining and then we welded two pieces of the same type of metal in the form of cylinder (entrance and outlet water) , Abrasive, extrusion and welding to form a cooling pipe. As shown in the following pictures in order

Figure 3.3: Cooling tube manufacturing processes .

3.5.2 Supply of exhaust gas conveyor :

Cut a copper pipe length of 45 cm and diameter of 3 cm and painted with a substance that prevents copper oxidation .

Figure 3.4: Design of exhaust pipe.

3.5.3 collection of components mentioned earlier:

The inner pipe of the exterior was assembled in a silver-welded manner and checked to ensure that there was no leakage of the components. As shown in the following picture

Figure 3.5: Pipe welding with each other .

3.5.4 The final stage o processing EGR :

The final phase was an addition to the exterior design and the addition of 4 valves on each entrance and outlet to control the flow of water and gas, and because the nature of the project needs to compare the EGR cooled with the traditional EGR It will take readings in the coolant EGR Then close the water valves (cooling cut) and take new readings and compare them. In addition to the work of the face of the paint design and show well on the surface .

Figure 3.6: Coating heat exchanger.

3.6 Method of Connecting :

The current EGR cooler has two entrances, one for exhaust gas and the other for water. It also has two exit outlets for gas and another for water. The EGR cooler is connected as follows: We connect the exhaust gas outlet from the engine to the exhaust gas entrance inside the EGR cooler and supply the EGR cooler with a cooling line tank the water on the engine and connect the outlet to the EGR cooler (Exhaust gas outlet) with the air inlet into the engine first enters the gas from the entrance and passes through the EGR cooler and through the EGR cooler inside the project is subjected to cooling through the water pipes and during the passage of low temperature and reduce nitrogen oxide and then passes to The entrance to the manifold and it enters the combustion chamber again.

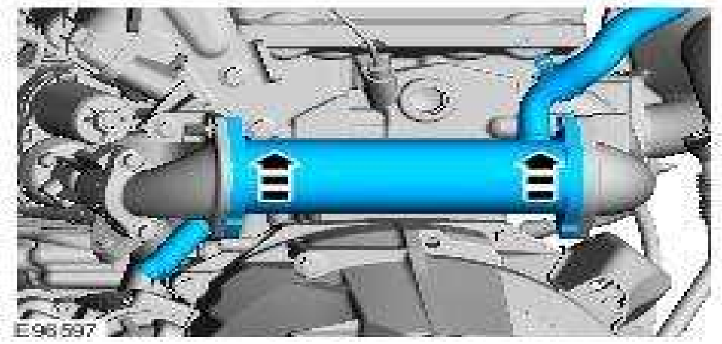


Figure 3.7:Connected EGR cooler.

3.7 Components:
The project consists of the following parts:

1) Diesel engine 6 cylinder.
2) Collectionof stainless steel pipes.
3) Engine cooling liquid.
4) Exhaust gas inlet chamber.
5) Exhaust gas exitchamber.
6) Cooling water intake.
7) Cooling water exit.
8) Metal cover.

3.8 Experimental Apparatus:

3.8.1 Four Gas analyses:
Is a device used to measure oxygen in the case of incomplete combustion, which measures the ratio of the presence of each (O_2, CO, CO_2 and NO_X).Figure 3.10.2.

Purpose: Exhaust gas analysis helps reduce engine performance, know the percentage of non-b\urning oxygen and know the mixing ratio of fuel (ideal, rich, lean).

Figure 3.8: Four Gas analyzer.

*NOTE :This device is available in the university but does not work so we will search for another device outside the university.

3.8.2 Thermocouples:

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 .The engine is coupled with three thermocouples.

$$C_{P/a} \, . m_a . t_a + C_{P/EGR} \, . m_{EGR} . t_{EGR} = C_{\frac{P}{m}} . m_m . t_m \qquad (3.16)$$

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 ,
- $C_{\frac{P}{m}}$: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 ,
- m_a : air mass flow ,
- m_{EGR} : recycled exhaust gases mass flow , and
- m_m : mixture mass flow .

To measure the temperatures of the intake air, 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 [20]:

$$EGR\% = \frac{\dot{m}_{EGR}}{\dot{m}_{(ma+mEGR)}} * 100 \qquad (3.17)$$

Purpose : To measure the flow rate EGR ratio.

3.8.3 Airflow meter :

A device that measures the air speed of the engine, its flow and its temperature air .

Figure 3.9: Airflow meter.

3.9 System Work:

3.9.1 Engine testing stage:

Conducting a full examination of all parts of the engine and diagnosing all engine failures and there were a lot of engine faults starting from the cooling cycle and injection system and other problems will be discussed in detail in this chapter.

3.9.2 Maintenance of the cooling system:

The cooling system was diagnosed by controlling the engine temperature and coolant temperature, observing the pipes where there was leaking in some of the water lines and changing them, separating the complete radiator and cleaning.

3.9.3 Check injection system:

Many problems in the injection system found several in this system where there was a defect in the diesel pump in terms of pressure inside the pump and in terms of distribution of diesel on the injector and some problems in the internal filling as there was a problem in some injector and based on this we In the following steps:

3.9.4. Check injector:

Examined the injector where there was a stirring in some of them and we inflated to remove this sediment on the inlet of the injector.

3.9.5 Timing calibration

At this stage , have adapted the time of the spray and the piston location TDC or BDC Where signs on the crankshaft and on the engine sieve and there was a mistake in these signs where there was a delay in fueling a few degrees . removed one of the injectors and put a screwdriver in place and moved the toothed crankshaft .

Figure 3.9: engine

3.10 Summary:

Briefly, the present project provides an EGR cooler for diesel and other engines that may include an improved core structure.

The end result of the process of reducing the temperature of the engine will help to reduce the reaction between nitrogen and oxygen and weaken the process of union between them, which is generated by the combination of harmful and toxic nitrogen oxides.

It is worth mentioning that the process of reducing the engine temperature "combustion chambers" has a positive role in reducing the chances of the sound of roads and the accuracy of the engine, and these methods is a destructive factor of the engine in general.

Chapter 5Calculation

5.1 Clarify the process used in calculations:

Was calculated Air mass flow and Recycled exhaust gases mass flow at different engine number of engine cycles (rpm), Through the device Airflow meter through which we got the speed of both the air inside the engine and the speed of the part of the recycled exhaust gasBased on the speed obtained, we calculated the flow of both the exhaust gas and the air with the control at the angle of exhaust gas flow through the Stopcock. Flow was calculated in the following stages:

5.1.1 Air mass flow:

Was calculated Air mass flow using an Airflow meter, in which we calculated the velocity of airflow the basis that external conditions were ideal.

Note: We could not use another device for air flow more efficiently because it is not available in the university, so we found this method to calculate the airflow flow velocity

Figure 5-1 Air mass flow with different (rpm)

We have compensated the denominator Air mass flow in the equation below to calculate velocity of airflow.

$m_{air} = \rho_{air} * V_{air} * A_{air}$ (5.1)

ρ: Density [g/L]

V: velocity [m/sec]

A: area [m^2]

Note: Air density and air intake section area are constants

٥.١.٢ Recycled exhaust gases mass flow:

We calculated the value of recycled exhaust gases mass flow for the exhaust gas by calculating velocity recycled exhaust gases at different angles of the flow

Note: The exhaust gas flow angles are controlled by a Stopcock

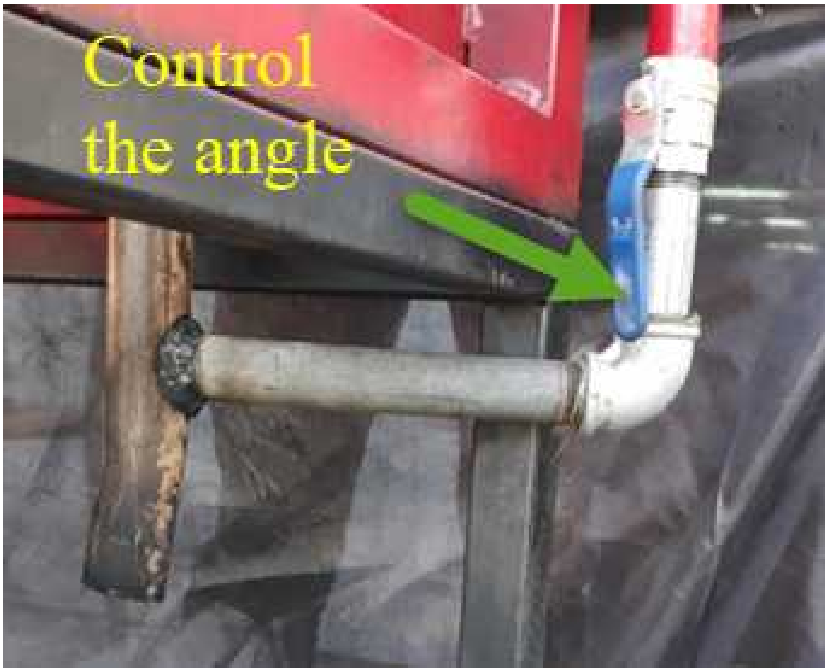


Figure 5-2 recycled exhaust gases mass flow with different angle

We have compensated the denominator Air mass flow in the equation below to calculate velocity of airflow

$$m_{EGR} = \rho_{EGR} * V_{EGR} * A_{EGR} \quad (5.2)$$

ρ: Density [g/L]

V: velocity [m/sec]

A: area [m^2]

Note: densityrecycled exhaust gases and**intake section areaare constants**

5.1.3 Diesel combustion equation with air:

$$C_XH_Y + a\ O_2 + 3.76N_2 \rightarrow yCO_2 + xH_2O\ g + a\ 3.76N_2 \quad (5.3)$$

A combination of exhaust gases is produced from the reaction of the fuel to the airof these gases (N_2, CO_2, O_2, CO and other gases) and different gas ratios depending on the nature of the interaction.

To calculate the mass of Diesel we need to use equation (5.3) so we need the actual chemical formula of Diesel which it C12.381 H22.1739 .

Here, we worked to balance the gasoline stoichiometric combustion equation, we get that the theoretical air is 17.9241 [gr air / gr diesel]

C12.381 H22.1739+ ath(O2 + 3.76 N2) $\rightarrow$ x H2O + y CO2 + z N2 (5.1a)

C balance: y=12.381

H balance: 2*x=22.1739 $\rightarrow$ x=11.086

O balance: 2×ath= x + 2×y $\rightarrow$ ath=17.9241

N balance: 2×3.76× ath=2×z $\rightarrow$ z=67.394

So the following equation represents the net equation of stoichiometric combustion of diesel (λ=1):

C12.381 H22.1739 + 17.9241(O2 + 3.76 N2) $\rightarrow$ 11.086 H2O +12.38CO2 +67.394N2

(2.9b)

But in the actual combustion λ variable (lean or rich) so we multiply the theoretical air by factor represent the excessive air ratio :

C12.381H22.1739+λ×17.9241(O2+3.76N2) $\rightarrow$ 11.086H2O+12.38CO2+λ×67.394N2

(2.9c)

5.2 Calculation ratio EGR recycled

The percentage of recycled gases is calculated according to the following equation

$$EGR\% = \frac{\dot{m}_{EGR}}{\dot{m}_{(ma+mEGR)}} * 100 \qquad (5.4)$$

In order to calculate the ratio EGR, It is necessary to refer to the following equation to calculate the air mass flow and recycled exhaust gases mass.

$$C_{P/a} . m_a . t_a + C_{P/EGR} . m_{EGR} . t_{EGR} = C_{\frac{P}{m}} . m_m . t_m \qquad (5.5)$$

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 ,
- $C_{\frac{P}{m}}$: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.
- m_a : Air mass flow.
- m_{EGR} : recycled exhaust gases mass flow.
- m_m : Mixture mass flow.

5.2.1 Calculation Air mass flow :

In order to calculate air mass flow, we must refer to the following equation

$m_{air} = \rho_{air} * V_{air} * A_{air}$(5.6)

ρ: Density [g/L]

V: velocity [m/sec]

A: area [m^2]

Constant parameter:

a- ρ = 1.2 [g/L]
b- Area = 0.0191 [m^2]

Table 5-1: The air speed changes depending on the rpm change on the engine

number of engine cycles	850 rpm	1700 rpm	2600 rpm
velocity[m/sec]	6.9	12.3	17.1

Calculate Air mass flow when the number of engine cycles is different (rpm):

At 850 rpm

m = ρ*V*A

= 1.2*0.0191*6.9

= 0.158 [Kg/sec]

At 1700 rpm

m = ρ*V*A

= 1.2*0.0191*12.3

= 0.282 [Kg/sec]

At 2600 rpm

m = ρ*V*A

= 1.2*0.0191*17.1

= 0.392 [Kg/sec]

Table-5.2 this table shows a change air mass flow in the number of engine cycles:

number of engine cycles	850 rpm	1700 rpm	2600rpm
velocity[m/sec]	6.9	12.3	17.1
m [Kg/sec]	0.158	0.282	0.392

5.2.2 Calculation recycled exhaust gases mass flow:

In order to calculate recycled exhaust gases mass flow, we must refer to the following equation.

$$m_{EGR} = \rho_{EGR} * V_{EGR} * A_{EGR} \quad (5.7)$$

ρ: Density [g/]

V: velocity [m/sec]

A: area [m^2]

Constant parameter:

c- ρ = 1.2766 [g/L]
d- Area = 1.2766 *10^$^{-3}$ [m^2]

Table 5-3 this table shows the change in the speed of the recycled gas and the gas flow angle at 1700 rpm:

Angle	0.0°	30°	60°	90°
velocity[m/sec]	0.0	10.5	19	29

Calculate recycled exhaust gases mass flow when the angle is different:

At angle 90°

V =29 m/s

m_1=1.2766*29* 1.232*10^$^{-3}$

= 0.0456 [Kg/sec]

At angle 60°

V =19 m/s

m_2 = 1.2766*19* 1.232*10^$^{-3}$

=0.02988 [Kg/sec]

At angle 30°

V =10.5 m/s

m_3 = 1.2766*10.5* 1.232*10^$^{-3}$

=0.01604 [Kg/sec]

Table 5-4 this table shows a change recycled exhausts gases mass flow in the speed of the engine at 1500 rpm:

Angle [deg]	0.0°	30°	60°	90 °
velocity[m/sec]	0.0	10.5	19	29
m [Kg/sec]	0.0	0.01604	0.02988	0.0456

5.2.3 Calculation Mixture mass flow:

In order to calculate Mixture mass flow we must return to the equation (5.5)

C

$$m_m = (C_{P/a} \, . \, m_a . \, t_a \; + C_{P/EGR} \, . \, m_{EGR} . \, t_{EGR}) / (C_{\frac{P}{m}} * t_m \;)$$

Table 5-5 this equation is solved by reference to the values previously found at 90° and 1700 rpm:

	Air	EGR gas
C_P [KJ/Kg]	1	1.0281
T [K]	298.3	*453*
m [Kg/sec]	0.282	0.0456

Consideration:

C_P = 1.004215 [KJ/Kg]

t_m = 321.8 [K]

$$m_m = (C_{P/a} \, . \, m_a . \, t_a \; + C_{P/EGR} \, . \, m_{EGR} . \, t_{EGR}) / (C_{\frac{P}{m}} * t_m \;)$$

= (1*0.282*298.3 +1.0281* 0.0456*453)/(1.004215*321.8)

= 0.31188 [Kg/sec]

Stability of the number of engine cycles and changing the angle:

Table 5-6 Calculate mixture mass flow when at 60° and 1700 rpm:

	Air	EGR gas
C_P [KJ/Kg]	1	1.0281
T [K]	298.3	453
m [Kg/sec]	0.282	0.02988

Consideration:

C_P = 1.004215 [KJ/Kg]

t_m = 321.8 [K]

$$m_m = (C_{P/a} \, . \, m_a . \, t_a + C_{P/EGR} \, . \, m_{EGR} . \, t_{EGR}) / (C_{\frac{P}{m}} * t_m)$$

= (1*0.282*298.3 +1.0281* 0.02988*453) / (1.004215*321.8)

= 0.299 [Kg/sec]

Table 5-7 Calculate mixture mass flow when at 30° and 1700 rpm:

	Air	EGR gas
C_P [KJ/Kg]	1	1.0281
T [K]	298.3	453
m [Kg/sec]	0.282	0.01604

Consideration:

C_P = 1.004215 [KJ/Kg]

t_m = 321.8 [K]

$$m_m = (C_{P/a} \, . \, m_a . \, t_a + C_{P/EGR} \, . \, m_{EGR} . \, t_{EGR}) / (C_{\frac{P}{m}} * t_m)$$

= (1*0.282*298.3 +1.0281* 0.01604*453) / (1.004215*321.8)

= 0.279 [Kg/sec]

Table 5-8 this table shows the effect of changing the gas flow angle on Mixture mass flow at 1700 rpm

Angle [deg]	m_m[Kg/sec]
0.0°	0.0
30°	0.279
60°	0.299
90°	0.31188

Angle stability when changing the number of engine cycles

Table 5-9 Calculate mixture mass flow when at 90° and 850 rpm:

	Air	EGR gas
C_P [KJ/Kg]	1	1.0281
T [K]	298.3	453
m [Kg/sec]	0.158	0.0456

Consideration:

C_P = 1.004215 [KJ/Kg]

t_m = 321.8 [K]

$$m_m = (C_{P/a} \, . m_a . t_a + C_{P/EGR} \, . m_{EGR} . t_{EGR}) / (C_{\frac{P}{m}} * t_m)$$

= (1*0.158*298.3 +1.0281* 0.0456*453) / (1.004215*321.8)

= 0.209 [Kg/sec]

Table 5-10 Calculate mixture mass flow when at 90° and 2600 rpm:

	Air	EGR gas
C_P [KJ/Kg]	1	1.0281
T [K]	298.3	453
m [Kg/sec]	0.392	0.0456

Consideration:

C_P = 1.004215 [KJ/Kg]

t_m = 321.8 [K]

$$m_m = (C_{P/a} \, . m_a . t_a + C_{P/EGR} \, . m_{EGR} . t_{EGR}) / (C_{\frac{P}{m}} * t_m)$$

= (1*0.392*298.3 +1.0281* 0.0456*453) / (1.004215*321.8)

= 0.427 [Kg/sec]

Table 5-11 this table shows the effect of changingNumber of engine (rpm) on mixture mass flowat 90°:

RPM[rev/min]	m_m[Kg/sec]
850	0.209
1700	0.31188
2600	0.427

Return to the equation (5.2):

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

- Rate of EGR:

Stability of the number of engine cycles and changing the angle at 1700 rpm

1. Rate of EGR at 30° deg.

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.01604)*100 / (0.279)

EGR %= 5.7

2. Rate of EGR at 60° deg.

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.02988)*100 / (0.299)

EGR %= 9.99

3. Rate of EGR at 90° deg.

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.0456)*100 / (0.31188)

EGR %= 14.52

Angle stability when changing the number of engine cycles at 90°

1. Rate of EGR at 850 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.0456)*100 / (0.209)

EGR %= 21.82

2. Rate of EGR at 1700 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.0456)*100 / (0.31188)

EGR %= 14.62

3. Rate of EGR at 2600 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.0456)*100 / (0.427)

EGR %= 10.68

Angle stability when changing the number of engine cycles at 60°

1. Rate of EGR at 850 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.02988)*100 / (0.1878)

EGR %= 15.9

2. Rate of EGR at 1700 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.02988)*100 / (0.31188)

EGR %= 9.58

3. Rate of EGR at 2600 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.02988)*100 / (0.422)

EGR %= 7.1

Angle stability when changing the number of engine cycles at 30°

1. Rate of EGR at 850 rpm

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.01604)*100 / (0.174)

EGR %= 9.2

2. Rate of EGR at 1700 rpm.

$$GR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.01604)*100 / (0.298)

EGR %= 5.4

3. Rate of EGR at 2600 rpm.

$$EGR\% = \frac{m_{EGR}}{m_{(ma+mEGR)}} * 100$$

EGR %= (0.01604)*100 / (0.408)

EGR %= 3.9

Table 5-12Variable flow ratios EGR when the number of different engine cycles and different angles:

Rpm [rev / min]	%EGR at 90°	%EGR at 60°	%EGR at 30°
850	21.82	15.9	9.2
1700	14.62	9.56	5.4
2600	10.68	7.1	3.9

This chart shows a change in the flow ratio EGR when the number of different engine cycles and angles are different:

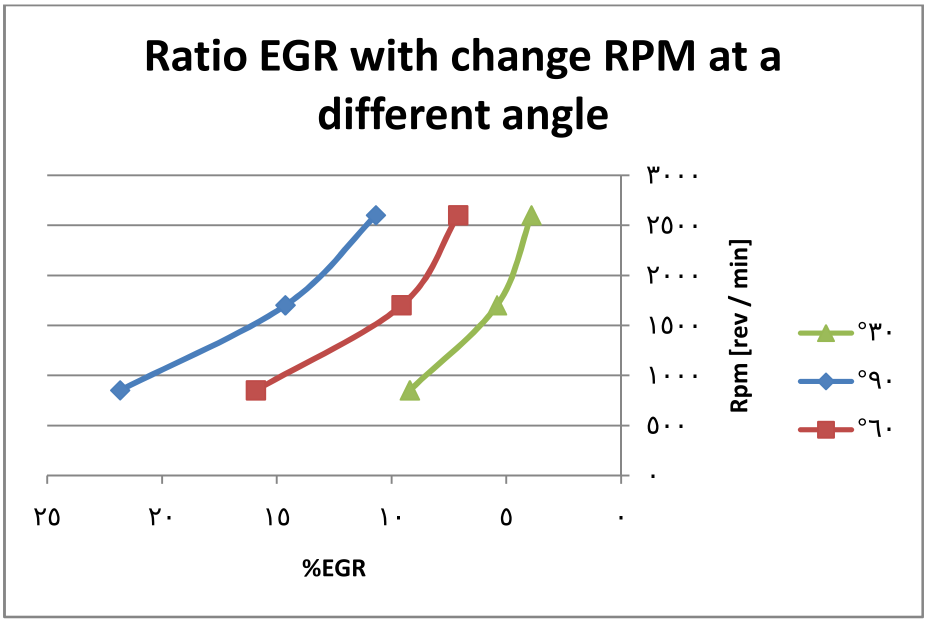


Figure 5-3 Ratio EGR with changes RPM at a different angle.

This chart shows a change mixture mass flow at 90 angles and the number of different engine cycles

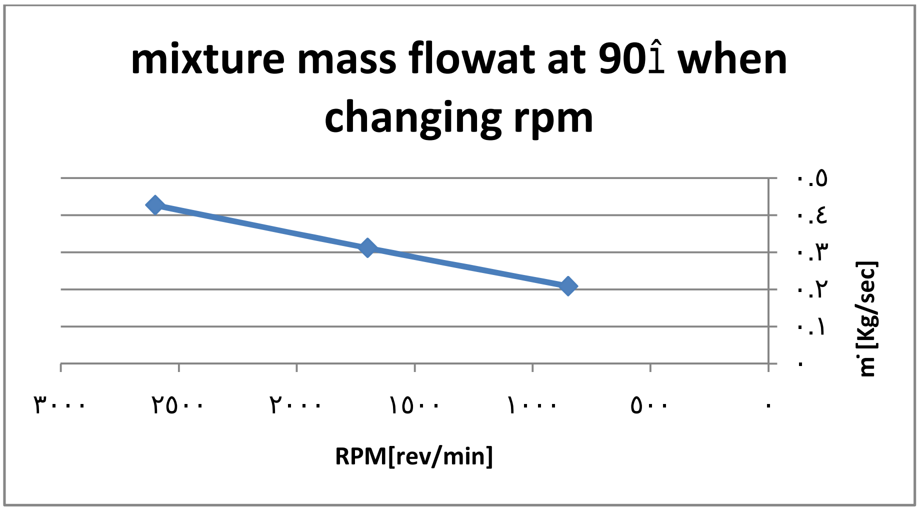


Figure 5-4 mixture mass flow at 90° when changing rpm

.

This chart shows a change Mixture mass flow when the number of cycles of a fixed engine (rpm) and the angle changes.

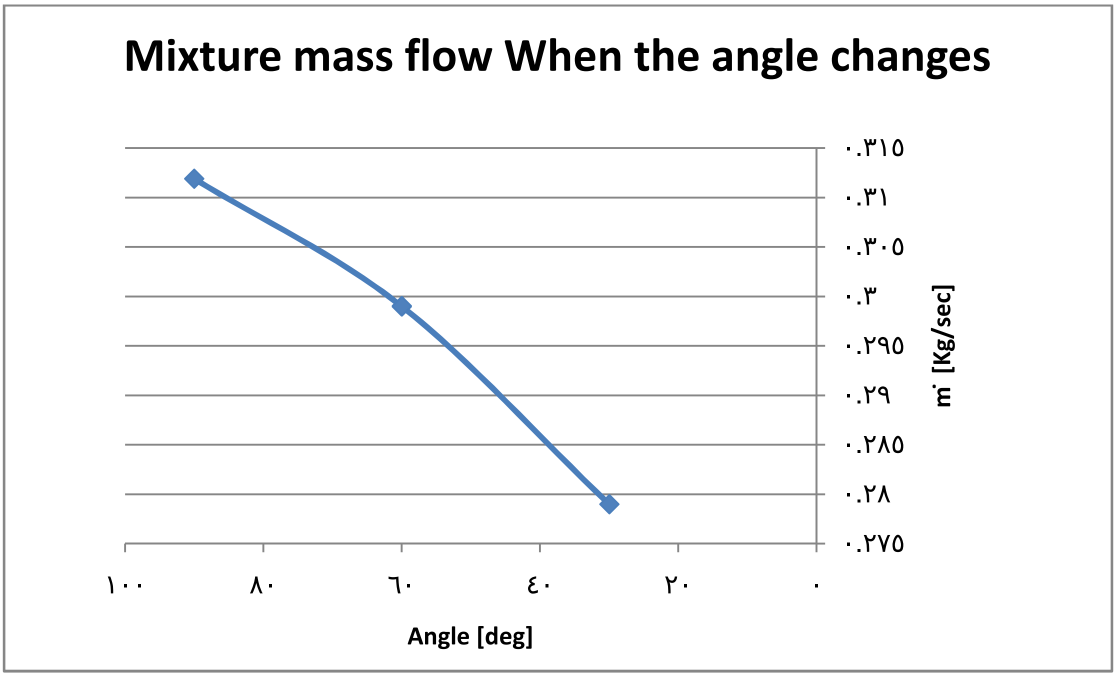


Figure 5-5 Mixture mass flow When the angle changes

This chart shows a change recycled exhaust gases mass flow when the number of cycles of a fixed engines (rpm) and the angle changes

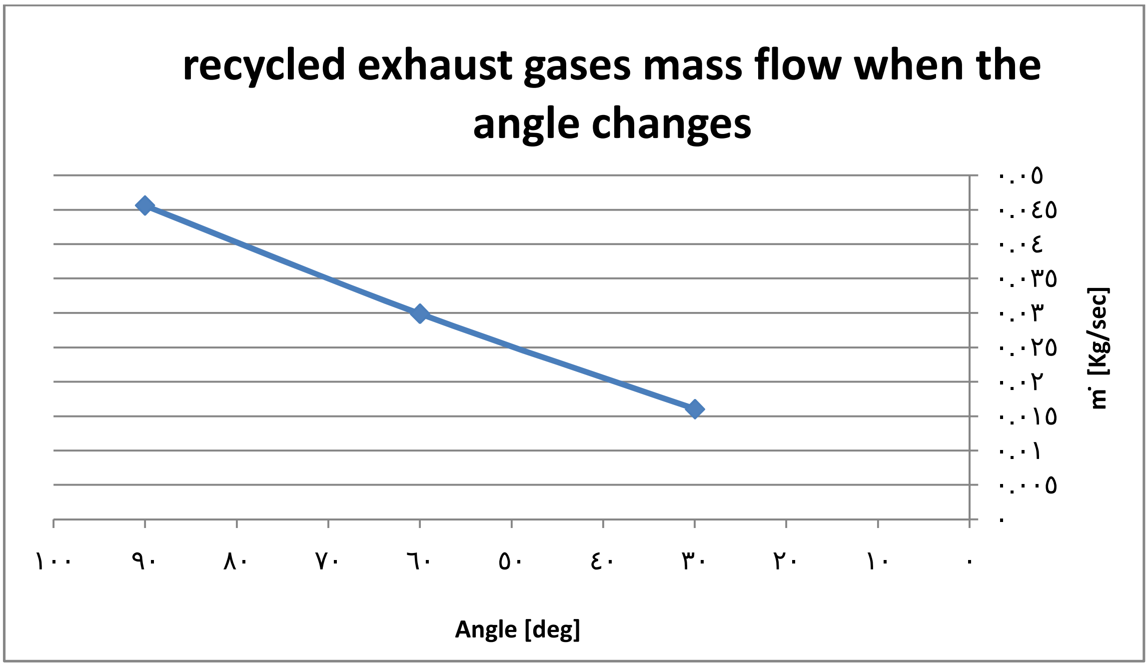


Figure 5-6 recycled exhaust gases mass flow when the angle changes.

This chart shows a change Air mass flow when the number of engine cycles changes at a fixed angle 90°

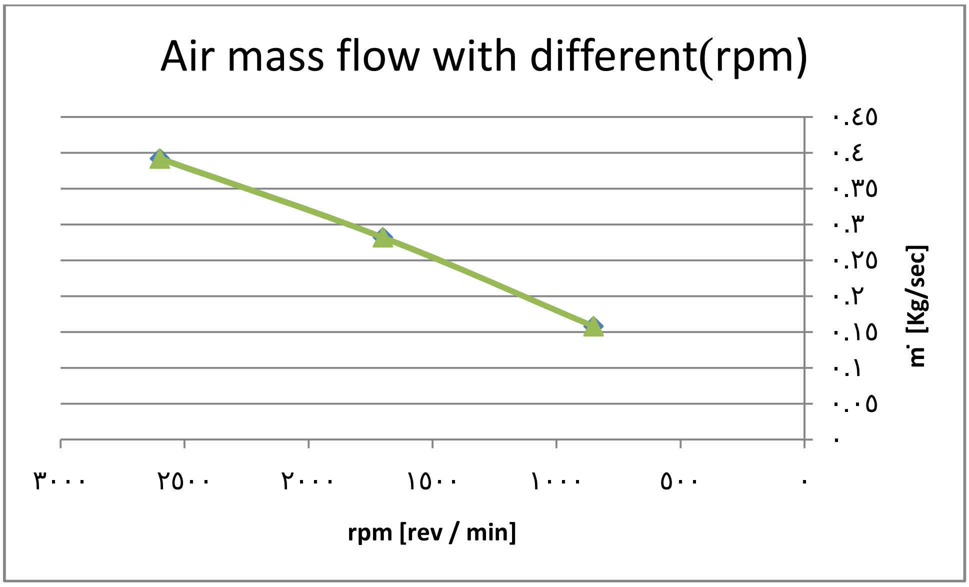


Figure 5-7 Air mass flow with different(rpm)

.

5.3 Effects of EGR cooler on exhaust gases:

Where we studied the effect EGR cooler on the emissions from the engine and its impact on reducing these emissions, which have a negative impact on humans and the environment where we used a device Gas analyzer. Through which we reached the extent of reduction EGR cooler these emissions

Where we experimented with emissions from the engine with EGR Traditional and without EGR and EGR cooler and we found a relationship showing us the proportion of gases emitted in the three cases (without EGR,with EGR,EGR cooler).

5.4.1 Effect EGR cooler on CO:

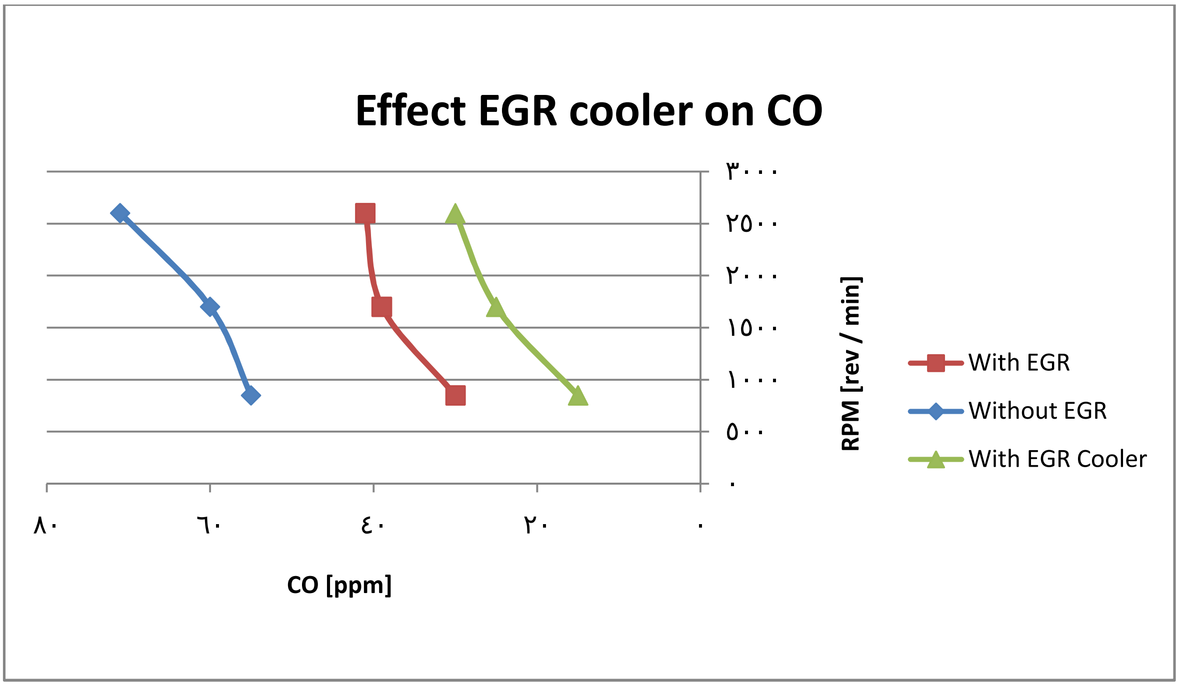


Figure 5-8 Effect EGR cooler on CO

Table 5-13 Effect EGR cooler on CO at constant angle.

RPM [rev/ min]	850	1700	2600
Without EGR	55	60	71
With EGR	30	39	41
With EGR cooler	15	25	30

In the case of non-connect EGR, It gives the highest value of (CO) which is 71 ppm. In the case of the connect of EGR traditional, give the lowest value of (CO) is 30 ppm. In the case of the connect of coolant EGR, Give less ratio than of (CO) is 15 ppm, with Change speeds.

5.4.2 Effect EGR cooler on NO2:

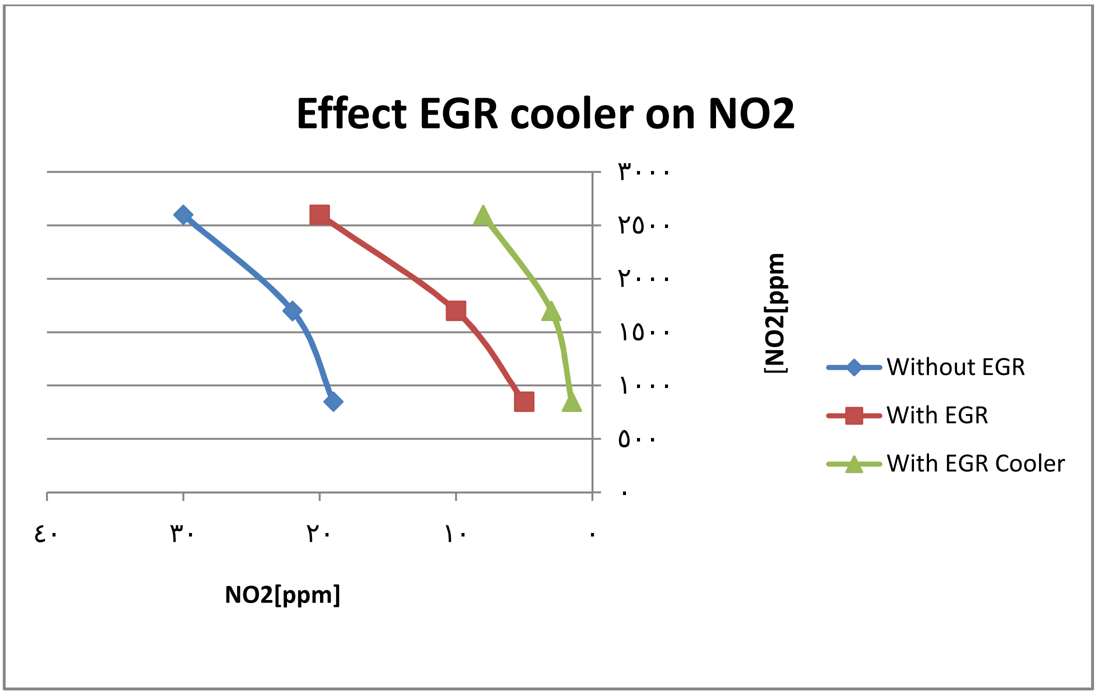


Figure 5-9 Effect EGR cooler on NO2

In the case of non-connect EGR , It gives the highest value of (NO_2) which is 30 ppm . In the case of the connect of EGR traditional, give the lowest value of (NO_2) is 5ppm . In the case of the connect of coolant EGR ,Give less ratio than of (NO_2) is 4 ppm , with Change speeds.

Table 5-13 Effect EGR cooler on NO2 at constant angle.

RPM [rev/ min]	850	1700	2600
Without EGR	19	22	30
With EGR	5	10	20
With EGR cooler	1.5	3	8

5.4.3 Effect EGR cooler on NOx:

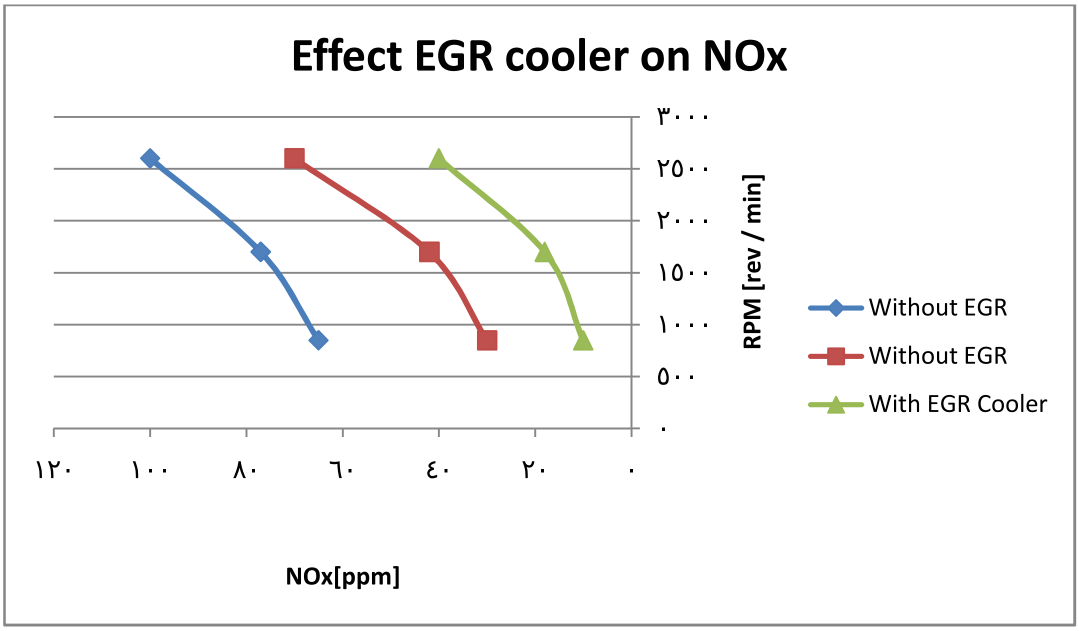


Figure 5-10 Effect EGR cooler on NOx

In the case of non-connect EGR , It gives the highest value of nitrogen oxide(NO_X) which is 100 ppm . In the case of the connect of EGR traditional, give the lowest value of (NO_X) is 30 ppm . In the case of the connect of coolant EGR, Give less ratio than of (NO_X) is 20 ppm , with Change speeds.

Table 5-1٤ Effect EGR cooler on NOx at constant angle.

RPM [rev/ min]	850	1700	2600
Without EGR	65	77	100
With EGR	30	42	70
With EGR cooler	10	18	40

Effect EGR cooler on NO:٥.٤.٤

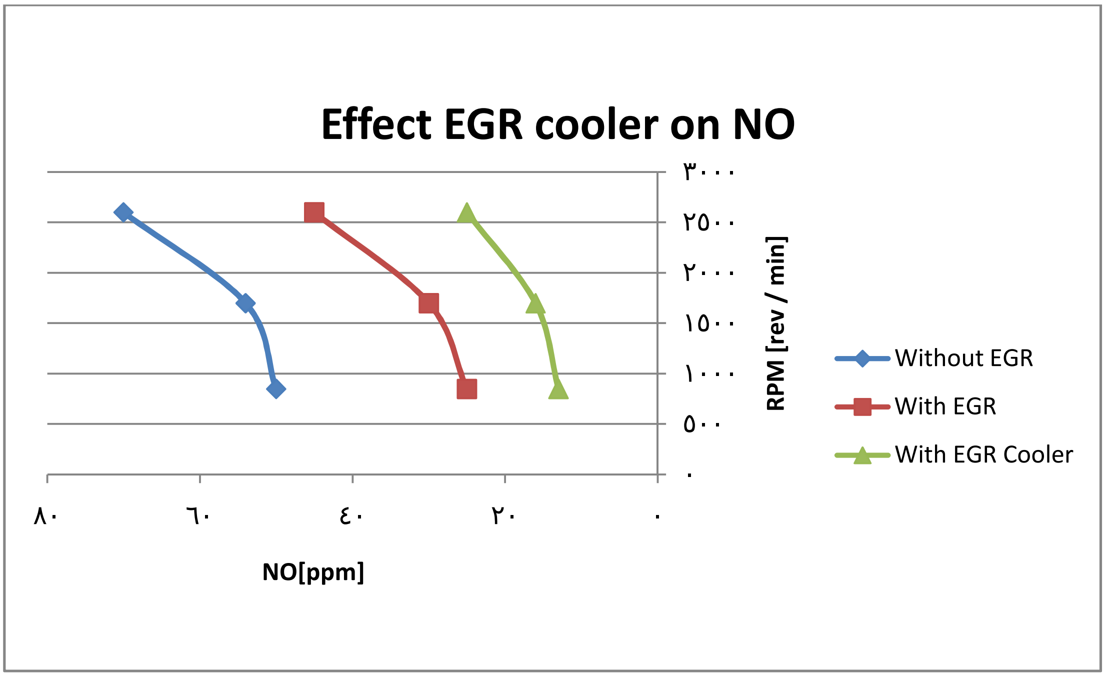


Figure 5-11 Effect EGR cooler on NO

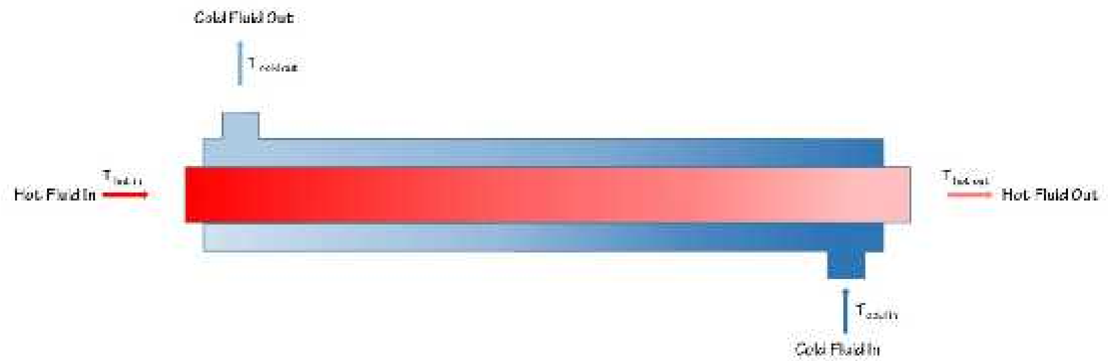
In the case of non-connect EGR , It gives the highest value of (NO) which is 70 ppm . In the case of the connect of EGR traditional, give the lowest value of (NO) is 25 ppm . In the case of the connect of coolant EGR ,Give less ratio than of (NO) is 12 ppm , with Change speeds

Table 5-15 Effect EGR cooler on NO at constant angle.

RPM [rev/ min]	850	1700	2600
Without EGR	50	54	70
With EGR	25	30	45
With EGR cooler	13	16	25

5.٤Heat exchanger:

We calculated the temperature of the exhaust gas and the coolant temperature, which is the water by a thermocouple sensor that converts heat to volts and converts the voltage to its readers on the screen.



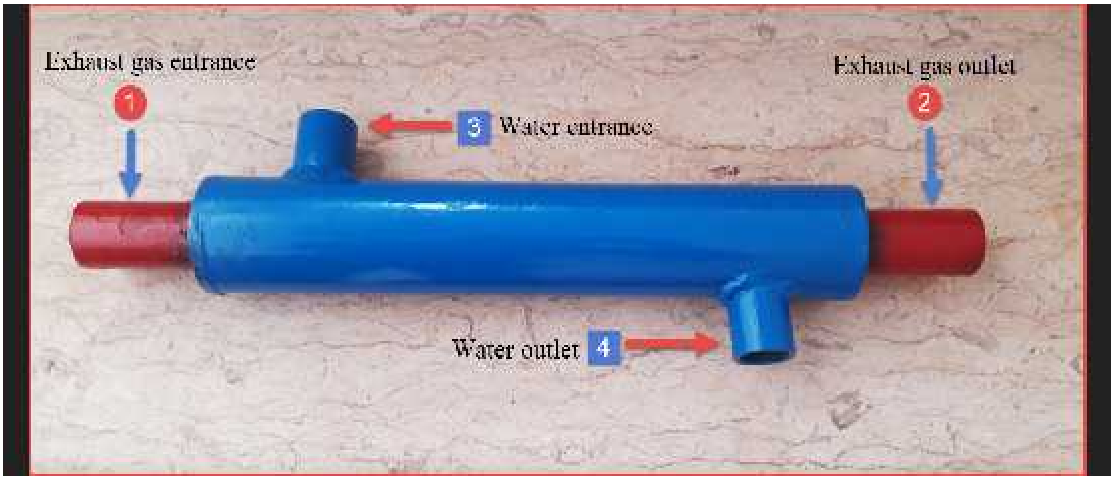


Figure 5-12 Heat exchangers (EGR cooler)

Table 5-16 Heat inlet and outlet exhaust and cooling water.

Temperature	Value[K]
$T_{in\ cooler}$	٣٠٥
$T_{out\ cooler}$	٣٥١
$T_{in\ gas}$	٥٣٢
$T_{out\ gas}$	٤٨٣

References:

1- Ladommatos, N., S.M. Abdelhalim., H. Zhao., Z. Hu., (1997). “The Dilution, Chemical,and Thermal Effects of Exhaust Gas Recirculation on Diesel Engine Emissions – Part 4:Effect of Carbon Dioxide and Water Vapour”, SAE Paper No. 971660.

2- Heywood, J.B. (1988). *Internal combustion engine fundamentals* Important-EGR-componat New York: McGraw-Hill.2016.

3- Tomazic, D., A. Pfeifer., (2002). “Cooled EGR – A Must or an Option for 2002/04”,SAE Paper No. 2002-01-0962.

4-Global Journal of Researches in Engineering Automotive Engineering Volume 12 Issue 2 Version 1.0 Year 2012 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Inc. (USA) Online ISSN: 2249-4596 & Print ISSN: 0975-5861

5- Jacobs T .,the impact of exhaust gas recirculation on performance and emission of heavy-duty diesel engine 2003.(0-14).

6- Zheng, M., Reader, G., Hawley, J. (2004). "Diesel Engine Exhaust Gas Recirculation – AReview on Advanced and Novel Concepts", International Journal of Energy Conversionand Management, 45(6), 883-900.

7- Ladommatos, N., S.M. Abdelhalim., H. Zhao., Z. Hu., (1997). “The Dilution, Chemical,and Thermal Effects of Exhaust Gas Recirculation on Diesel Engine Emissions – Part 3:Effects of Water Vapour”, SAE Paper No. 971659.

8- Ladommatos, N., S.M. Abdelhalim., H. Zhao., Z. Hu., (1997). “The Dilution, Chemical,and Thermal Effects of Exhaust Gas Recirculation on Diesel Engine

9- Ladommatos, N., S.M. Abdelhalim., H. Zhao., Z. Hu., (1996). “The Dilution, Chemical,and Thermal Effects of Exhaust Gas Recirculation on Diesel Engine Emissions – Part 1:Effect of Reducing Inlet Charge Oxygen”, SAE Paper No. 961165.

10- Ladommatos, N., S.M. Abdelhalim., H. Zhao., Z. Hu., (1996). “The Dilution, Chemical,and Thermal Effects of Exhaust Gas Recirculation on Diesel Engine Emissions – Part 2:Effects of Carbon Dioxide”, SAE Paper No. 961167.

11-Kumar V., Design of an Experimental EGR System for two Cylinder Diesel Engine [2005],55-78

12-http://kb.engsoftware.com/display/ESKB/Difference+Between+the+Effectiveness-NTU+and+LMTD+Methods

.