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EXHAUST GAS RECIRCULATION EFFECT ON COMBUSTION AND EMITTED NO_X IN A SPARK IGNITION ENGINE USING HIGH OCTANE NUMBER FUEL

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ABSTRACT

Pollutants emitted from internal combustion engines cause significant environmental pollution, and the reduction of these pollutants is the goal of all. The deterioration of air quality is increasing year after year due to increasing the population and cars and low awareness of pollution reduction. In this study, the impact of recycling of exhaust gas in a spark ignition engine was tested on the NOx emitted from it, which is considered one of the most dangerous environmental pollutant. The results of the study showed that the brake specific fuel consumption increases by increasing the amount of the EGR interning the engine, also the brake thermal efficiency increases and the volumetric efficiency decreases with this increase. The NOx concentrations emitted are significantly reduced when high rates of EGR (15% and 20%) are added. The use of high octane fuel RON94.5 has helped to reduce the expected EGR damage, such as greater reduction in the specific fuel consumption, or a greater reduction in the volumetric efficiency.

Keywords: EGR; Octane number; Brake thermal efficiency; Brake specific fuel consumption; NO_X

تأثير إعادة تدوير غازات العادم على الاحتراق وعلى NOx في محركات الاحتراق الداخلي باستخدام وقود عالي الاوكتان

نور حسن عادل محمود صالح

الخلاصة

في هذه الورقة، الملوثات المنبعثة من محركات الاحتراق الداخلي تسبب تلوثا بيئا كبيرا، والتقليل من هذه الملوثات هو هدف الجميع. يزداد تدهور نوعية الهواء عاما بعد عام بسبب زيادة السكان والسيارات وضعف الوعي بالحد من التلوث. في هذه الدراسة تم اختيار تأثير أعادة تدوير غازات العادم في محرك لاشتعال بالشرر على NOx المنبعثة منه، والذي يعتبر أحد الملوثات البيئية الأكثر خطورة. بينت نتائج الدراسة أن استهلاك الوقود المكبحي يزداد مع زيادة كمية EGR الداخلة الى المحرك، وكما تزداد الكفاءة الحرارية المكبحية وتتناقص الكفاءة الحجمية مع هذه الزيادة. يتم تقليل تراكيز NOxالمنبعثة بشكل كبير عند أضافة كميات كبيرة من EGR (15% الى 20%). ساعد استخدام الوقود ذو العدد الاوكتاني العالي RON94.5 على تقليل الاضرار المتوقعة من EGR مثل خفض أكبر استهلاك الوقود أو تقليل أكبر في الكفاءة الحجمية.

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NOMENCLATURE

SI	Spark ignition
ON	Octane number
BP	Brake power
N	Engine speed
Tb	Brake torque
ho	Manometer reading
ρa	Density of air
Vf	Tube volume
ρf	Density of fuel
t	Time
$\dot{m}f$	Mass flow rate of fuel
LHV	Lower heating value
$\dot{m}a$	Mass flow rate of air
Vdis	Displaced volume
N	Number of working strokes per minute, n = N/2 for four - stroke cycle engines.
bsfc	Brake specific fuel consumption
CO	Carbon monoxide
CO_2	Carbon dioxide
UHC	Unburned hydrocarbons
NO_X	Nitrogen oxides
GEM	(Gasoline + Ethanol + Methanol)

Greek symbols

η_{bth}	Brake thermal efficiency
η_v	Volumetric efficiency

INTRODUCTION

Crude oil is the main source of fuel used in internal combustion engines, such as gasoline and diesel. This article is a depleted source in addition to the volatile prices began to concern the economic security of countries and pressure on the plans of governments Al-Maamary et al. (2017). Its burning causes a large environmental pollution caused till today to climate change and the phenomenon of global warming Al-Maamary et al. (2017). In order to regulate the environmental pollution, higher emissions standards are imposed consistently on vehicle engines operating in the United States and Europe M. L. Poulton (1994). Nitrogen oxides are formed at high concentrations when the temperature inside the cylinder exceeds (2000) K D. Tomazic and A. Pfeifer (2002). Both NO and NO_2 are collected together as NOx. There are some differences between these two polluters. Both gases are toxic, but nitrogen dioxide has a greater toxicity than NO. NO is formed during the combustion process in the front area of the flame, a high temperature zone. The main source of NO formation is nitrogen oxidation in the air. The reactions of the formation of nitric oxide begin with atomic oxygen, which consists of the breakdown of oxygen molecules at high temperature during the combustion process N. Ladommatos et al. (1998). Designers used many methods to reduce NOx emissions from spark ignition engines, including spark timing retardation, injecting water into the combustion chamber, and recycling the exhaust gas. Each method has its advantages and disadvantages R. Udayakumar et al. (2010). Exhaust gas recirculation (EGR) is one of the most effective techniques for NO_X concentration reduction in the combustion chamber by keeping temperature under control R. Pratibhu et al. (2013), A. Ibrahim et al. (2007). The EGR technique requires recirculating a fraction of exhaust gases into the intake manifold where it mixes with the fresh incoming charge (air and fuel) usually, immediately after the throttle G. H. Abd-Alla et al. (2001). M. S. Shehata et al. (2008) investigated the engine performance parameters and exhaust emissions from 4-stroke, 4- cylinder naturally aspirated SI engine with EGR at different ratios (0%, 5%, 7%, 8% and 10%). The study outcomes revealed that the (bsfc), UHC, CO emissions and exhaust gas temperature increased with increasing EGR. On contrast to brake power, (η_{bth}) and air to fuel ratio decreased with increasing EGR. Decreasing air to fuel ratio, combustion deterioration and efficiency losses largely attributed to the increase of pumping work with the increase of EGR. EGR improves the combustion qualities by increasing the inlet charge temperature, UHC and CO re-burned with using of EGR. T. Alger et al. (2011) studied reducing the emissions of NO_X and CO run with high levels of both cooled and hot EGR. The results showed that an improvement between 5% and 30 % in fuel consumption is possible, with the largest improvement occurring in the typical enrichment region. In addition, the results revealed that the EGR could reduce the knock, resulting in an improvement in combustion phasing. Finally, the high levels of EGR reduced the emission of CO by 30 % and of NO_X by to 80%. S. Ghosh and D. Dutta. (2012) investigated the effect of various EGR ratios (from 0% to 30%) on the engine performance and exhaust emissions parameters. The engine speed was taken constant at (1500) rpm with a commercial gasoline fuel of RON92. The results showed that the CO, UHC and NO_X emissions reduced by (62.4%, 52.02% and 71.45%), respectively with increasing the percentage EGR levels to 30% compared with 0% EGR. While, CO_2 increased by 15.84% with the increasing rate of 30% EGR compared with 0% EGR. Z. Salhab (2012) studied the effect of different EGR ratios on the emission and performance of four-stroke single cylinder hydrogen fueled SI engine with different excess air ratios. The effect of EGR on the NOx concentration and engine performance is similar to the addition of excess air. Both EGR and excess air dilute the unburned mixture. The results of the investigation depicted that the NO_X concentration were decreased by 72.94% with increasing EGR ratio. The mean effective pressure decreased by 21.19% with EGR compared without EGR. In addition, the maximum pressure of cylinder decreased by 19.59% with excess air ratio and 15% EGR compared to without EGR. P. T. Nitnaware et al. (2015) investigated the effect of EGR at different ratios (0%, 5%, 10% and 15%) on the performance parameters and exhaust emissions. There is a considerable reduction in NO_X in SI engine. The EGR is very much eco-friendly. The results showed that the brake power for gasoline reduced by (3%, 9%, and 13%) by the implementing (5%, 10% and 15%) EGR, respectively. Emission of NO_X very reduced by implementation of EGR from 45% to 90%, and CO increased due to the incomplete combustion. The emissions of UHC and CO_2 were increased by implementing EGR with engine than that of operating engine without EGR. P. P. Corresponding (2015) studied the effect of EGR on the emission of a single cylinder, four-stroke SI engine. The experimental results were obtained to study the emission characteristics by EGR using various catalytic coatings and different EGR flow rates. The results exhibited that the NO_X concentration reduced when the engine operated with cooled EGR. The maximum NOx reduction for copper-coated engine with 10% EGR was about 45 % lower than the standard engine. The other catalytic coatings, like chromium and nickel revealed the NO_X reduction of 7 % and 4 % lower than standard engine. L. Nahedh and M. Ali (2016) investigated the influence of using a pair of mixing ratios (10%) and (20%) of bioethanol to gasoline by adding (10%) cool and hot (EGR). The investigational work was conducted on a four-cylinder SI engine using different conditions of torque of engine, timing of spark, and speed. The outputs showed that the addition of (10%) ethanol raised the concentration of (NO_X) for the speeds of engine higher than (1600) rpm. The high temperature of combustion with greater available oxygen from ethanol led to such results. The EGR decreased the concentrations of (NO_X) obviously in comparison with (0%) and (10%) ethanol. The rates of decrease were (16%) and (6.9%) for cool and hot (EGR), correspondingly in comparison with the emitted NO_X from a gasoline engine having (0%) ethanol. The concentrations of NO_X were decreased by utilizing (20%) ethanol owing to the decrease in the blend LHV that decreased the temperature of combustion. The influence of EGR decreased the concentration of NO_X by (19.9%) and 10.46%) for cool and hot (EGR), correspondingly in comparison with the NO_X from the gasoline engine having (0%) ethanol. However, the influence of variable torques of engine on the (NO_X) at ethanol (0%, 10% and 20%) without and with the addition of cool and hot (EGR) was studied. Raising the torque of engine increased the temperature of combustion via the burning of more fuel, which resulted in higher concentrations of (NO_X). T. Onawale and T. O. Temitope (2017) studied the effect of mixing 2.6% EGR with intake mixture. The results showed a significant reduction in the exhaust gas temperature and the flame temperature of the engine by 22%. However, their experiments revealed an increment in the fuel consumption by 4.8%. As the engine speed decreased, the brake power reduced by 7.5%. The percentage of the flame temperature reduction was more than the brake power reduction. F. Xie et al. (2017) investigated the influence of hot EGR on the engine combustion, performance and particulate number emission in a SI (GDI) engine. Meanwhile, the different effects between cooled and hot EGR methods were compared, and the variations of fuel consumption and emissions under six engine operating conditions with different speeds and loads were analyzed. The results indicated that the (bsfc) increased, the engine fuel economy deteriorated with the increase of EGR ratio, and the (bsfc) of cooled EGR method increased obviously more than that of hot EGR method. When EGR ratio was 20%, the (bsfc) of cooled EGR was higher by 7% compared to the with cooled EGR. However, the NOx concentration of cooled EGR decreased about 36 ppm than that of hot EGR. M. T. Chaichan. (2018) studied the effect of hot and cool EGR with fixed percentage (10%) on the exhaust emission of multi cylinder SI engine fueled with three components (ternary) fuel consisted of gasoline, bioethanol and methanol. The results showed that the ternary blend offers relatively lower NOx and larger reduction in smoke when used alone than that with the Iraqi gasoline. The EGR addition to GEM blend reduced the NOx concentration remarkably and the smoke opacity rates at NOx a lesser extent than those with the gasoline and E85 blend. Cool EGR introduces a good NOx-smoke tradeoff at the tested cases. Furthermore, the addition of cooled EGR reduced the NOx concentrations by approximately 17.83% and 21.42% at variable speeds and by 44.9% and 62.57% at variable torques compared to those of Iraqi gasoline. Correspondingly, these additions also reduced the smoke opacity with about 22.24% and 14.83% at variable engine speeds and 21.44% and 14.11% at variable engine torques. The aim of this experimental work is to evaluate practically the effect of EGR use in a 4- cylinder engine fueled by high octane number gasoline (94.5). The interest will be concentrated on the resulted pollutants CO, UHC, and NOx. EGR is always used to control the NOx levels emitted and in this work, this point will be studied in much attention to verify this impact.

EXPERIMENTAL WORK

A spark ignition engine type Mercedes-Benz used was in the current study. The tested fuel was commercial grade with RON94.5. The detailed properties of the tested gasoline fuel used are given in Table (1). A hydraulic dynamometer was used to adjust the engine torque and to determine its load. The air enters the engine through an air box. An intake air orifice fixed on the box was used to measure the pressure difference between the atmosphere and the intake pressure. A marked glass bulb of known volume was used to measure the volumetric fuel consumption. The exhaust gas pollutants (such as CO, UHC, NO_X and CO_2) levels were measured using an Exhaust Gas Analyzer model (EGMA HG-550) with printer, Italy made. The exhaust gas temperatures were measured using thermocouples (type K) and a digital reader. Figure (1) shows the experimental rig, and Figure (2) is the schematic diagram of it. Table 2 lists the main technical specifications for the used engine.

EQUATIONS USED IN THE PRESENT STUDY

Brake power

$$Bp=\frac{2\pi*N*Tb}{60*1000} \tag{1}$$

Mass flow rate of air

$$\dot{m}_a=\frac{5*\sqrt{h_o}}{3600}*\rho_a \quad (Kg/sec) \tag{2}$$

Mass flow rate of fuel

$$\dot{m}_f=\frac{V_f\times\rho_f}{t\times 10^6} \qquad (kg/sec) \tag{3}$$

Brake spicefic fuel consumption

$$bsfc=\frac{\dot{m}f*3600}{bp} \tag{4}$$

Brake thermal efficiency

$$\eta_{bth}=\frac{bp}{\dot{m}f*LHV}*100\% \tag{5}$$

Volumetric efficiency

$$\eta_v=\frac{ma/\rho a}{vdis*n/60}*100\% \tag{6}$$

Ideal mass flow rate of air

$$\dot{m}_{air\ (ideal)}=\frac{vdis*n*\rho a}{60} \tag{7}$$

EGR SYSTEM

The EGR system consists of four main parts as follow: -

EGR Cooler: In order to reduce the exhaust gas temperature to the ambient temperature, a heat exchanger was manufactured for this purpose. The heat exchanger type is shell and coil with shell dimensions (35*30) cm as height and diameter. The coil pipe is copper with (1000*0.95*0.06) cm and (10) turns. The outlet gas from the cooler (parallel) is delivered to filter.

Filter: The filter duty is absorbing the moisture of gas after leaving the heat exchanger and then passing the gasses that have been filtered to flowmeters. The filter contains the silica gel with (1400) g.

Flowmeters: For measuring the mass flow rate of EGR, two flowmeters were used. The first flowmeter worked with low speeds from (0.6 to 6) m^3/h, while the second flowmeter worked with high speeds (6 to 60) m^3/h. The flowmeters were connected parallel with two control valves before each one to select the suitable one with respect to the test speed. The outlet gasses moved to mercury thermometer.

Thermometer: The EGR passes to a mercury thermometer that measured the temperature of the gases after being cooled which reaches approximately (30) C°, and moves to the intake manifold to be mixed with the incoming charge (air and fuel).
A plastic hose was used to connect the heat exchanger with filter and filter with flowmeters. A source tank with (1) m^3 capacity was utilized to calculate the heat exchange cooling water. EGR is defined as a mass percent of the total intake flow:

$$EGR\% = [m_{EGR}/m_i]*(100) \tag{8}$$

where,
m_i is the total mass flow into the cylinders.
m_{EGR} is the mass flow of EGR.

TEST PROCEDURE

In the experiments, variable EGR ratio (5%, 10%, 15% and 20%) and type of gasoline fuel RON94.5 were fueled to the engine. All performance tests were conducted at maximum and minimum loads for variable engine speeds. The engine speeds were varied from 1200 to 2700 rpm with intervals of 300 rpm. The air consumption, fuel consumption, engine speed, torque, exhaust gas temperatures, and exhaust emissions levels were taken at each tested speed. Each test process was repeated three times to confirm the repeatability. The values given in this study are the average of these results.

RESULTS AND DISCUSSION

Figure (3a, b) shows the variation of brake power with the engine speed for the tested gasoline fuel at different EGR ratios and loads. From the figure (3a), the outcomes revealed that the brake power decreased with increasing EGR ratio from (1200 to 2100) rpm. This reduction was very clear at 20% EGR ratio by (5.18%) compared to 0% EGR. At the minimum load, the effect of EGR was clear for the all ratios from (1200 to 2400) rpm. The brake power decreased at (5%, 10%, 15%, and 20%) EGR addition by (0.78%, 1.36%, 4.54% and 10.17%) compared to 0% EGR, respectively. This behavior contrasted with the researcher M. N. Syaiful and M.-W. Bae (2006) who observed that the brake power increased with increasing EGR ratio because it improves the combustion temperature. When the combustion temperature was increased, the reaction rate increased, and this causes an increase in the released energy. Figure (4a, b) presents the variation of (η_{bth}) with the engine speed for the tested gasoline fuel at different EGR ratios and loads. In the figure (4a), at the maximum load, the (η_{bth}) slightly decreased with the amount of EGR increase from (1200 to 2400) rpm very clear at 20% EGR ratio by (5.12%) compared to 0% EGR. This may be due to the fact that the amount of fresh oxygen available for combustion decreased due to replacement by EGR. However, this behavior in contrasted with the researcher S. Ghosh and D. Dutta. (2012). It was observed that the (η_{bth}) has slightly increased with the amount of EGR because with the increase in EGR rate, the specific heat capacity increased and the combustion temperature decreased by dilution, and this decreased the mixture burning velocity and increased the combustion duration. Many researchers have reported similar behavior on various types of engine and conditions P. P. Corresponding (2015), H. P. Tamilarasan, and M. Loganathan (2016). At the minimum load, the (η_{bth}) increased with increasing the EGR ratios at (5%, 10%, 15% and 20%) by (11.47%, 6.35%, 5.14% and 1%) compared to 0% EGR, respectively. This can be attributed to the dilution effect, which reduced the combustion heat release and detorated the flame propagation rate. Figure (5a, b) demonstrates the variation of (bsfc) with the engine speed for the tested gasoline fuel at different EGR ratios and loads. The results showed that the (bsfc) increased with increasing the ratio of EGR. This is may be due to the formation of rich mixture because of the less oxygen availability. At maximum and minimum load of gasoline fuel RON94.5, the (bsfc) increased at 20%, EGR by (17.63% and 66.03%) compared to 0% EGR, respectively and (1200) rpm. This behavior in contrast with the researchers Z. Salhab (2012), M. N. Syaiful and M.-W. Bae (2006) and H. P. Tamilarasan, and M. Loganathan (2016). who observed the improvement in the (bsfc) with increasing EGR. One of the main reasons for that effect is due to the reduction of pumping work. Again, due to the reduction of heat loss to the wall of the cylinder, the significant reduction in the burnt gas temperature improved the fuel consumption trends. Figure (6a, b) manifests the variation of (η_v) with the engine speed for the tested gasoline fuel at different EGR ratios and loads. Figure (6a) shows that the EGR has no clear significant effect on the (η_v) of the engine. But at the minimum load of RON94.5, the (η_v) increased by (5.49% and 5.39%) at (15% and 20%) EGR, respectively compared to 0% EGR at the engine speed (1200 to 2100) rpm. Figure (7a, b) shows the variation of the exhaust gas temperature with the engine speed for the tested gasoline fuel at different EGR ratios and loads. It was observed that the exhaust gas temperature decreased with the increasing in EGR ratio. The use of EGR reduced the oxygen from fresh air causing the reduction of combustion temperature. In the RON94.5, the exhaust gas temperature decreased at (5%, 10%, 15% and 20%) by (1.38%, 2.89%, 6.21%, 13.12%, 3.34%, 5.17%, 8.64% and 13.88%) at maximum and minimum load compared to 0% EGR, respectively. Figure (8a, b,) illustrates the variation of NO_X with EGR ratios for the tested gasoline fuel at different loads and constant speeds. The results showed that the NO_X concentration decreased significantly with EGR ratios for all cases. However, the outcomes revealed that the NO_X concentration increased with increasing the load. Very low NO_X can be obtained with higher EGR rates, because the combustion process delayed due to the higher dilution and reduced the oxygen concentration; increasing the amount of inert gas reduced the adiabatic flame temperature in the combustible mixture. Thus, it is the total burned gas fraction in the unburnt mixture in the cylinder (which consists of both the residual gas from the previous cycle and the EGR to the intake) that act as diluents. This indicated that the percentage of EGR rate has a significant effect on the NO_X formation rates. In figure (8a, b, c, d, e, f), the NO_X decreased at 20% EGR of gasoline fuel RON83 and RON94.5 at maximum and minimum load by [(85.71%, 100%), (82.27%, 87.2%), (64.97%, 75.83%), (70.08%, 62.86%), (23.40%, 76.74%), (100%, and 100%)] compared to 0% EGR, respectively.

CONCLUSIONS

The effects of engine speed variations on the performance and NO_x concentration of a SI engine using gasoline fuels with RON 94.5 and EGR ratios have been investigated experimentally. The conclusions from this work are summarized as follows:

1. The brake power for a maximum load of gasoline fuel RON94.5 at (1200 to 2100) rpm and 20% EGR reduced by (5.18%) compared to 0% EGR. At a minimum load of gasoline fuel RON94.5, the effect of EGR was too obvious at the all ratios from (1200 to 2400) rpm. Also, the brake power decreased at (5%, 10%, 15%, and 20%) EGR by (0.78%, 1.36%, 4.54% and 10.17%) compared to 0% EGR, respectively.
2. The decrease in (η_{bth}) at a maximum load of gasoline fuel RON94.5 from (1200 to 2400) rpm at 20% EGR ratio was (5.12%) compared to 0% EGR. At the minimum load, the (η_{bth}) increased with increasing the EGR ratios at (5%, 10%, 15% and 20%) by (11.47%, 6.35%, 5.14% and 1%) compared to 0% EGR, respectively.

3. The (bsfc) increased with increasing the EGR ratio for minimum and maximum load at (1200) rpm and 20% EGR by (17.63% and 66.03%) compared to 0% EGR, respectively.
4. The (η_v) increased by (5.49% and 5.39%) at (15% and 20%) EGR compared to 0% EGR at (1200 to 2100) rpm.
5. The exhaust gas temperature decreased at (5%, 10%, 15% and 20%) EGR by (1.38%, 2.89%, 6.21%, 13.12%, 3.34%, 5.17%, 8.64% and 13.88%) at maximum and minimum load compared with 0% EGR, respectively.
6. The NO_X decreased at 20% EGR at maximum and minimum load by [(85.71%, 100%), (82.27%, 87.2%), (64.97%, 75.83%), (70.08%, 62.86%), (23.40%, 76.74%), (100%, and 100%)] compared to 0% EGR, respectively at (1200 to 2700) rpm.

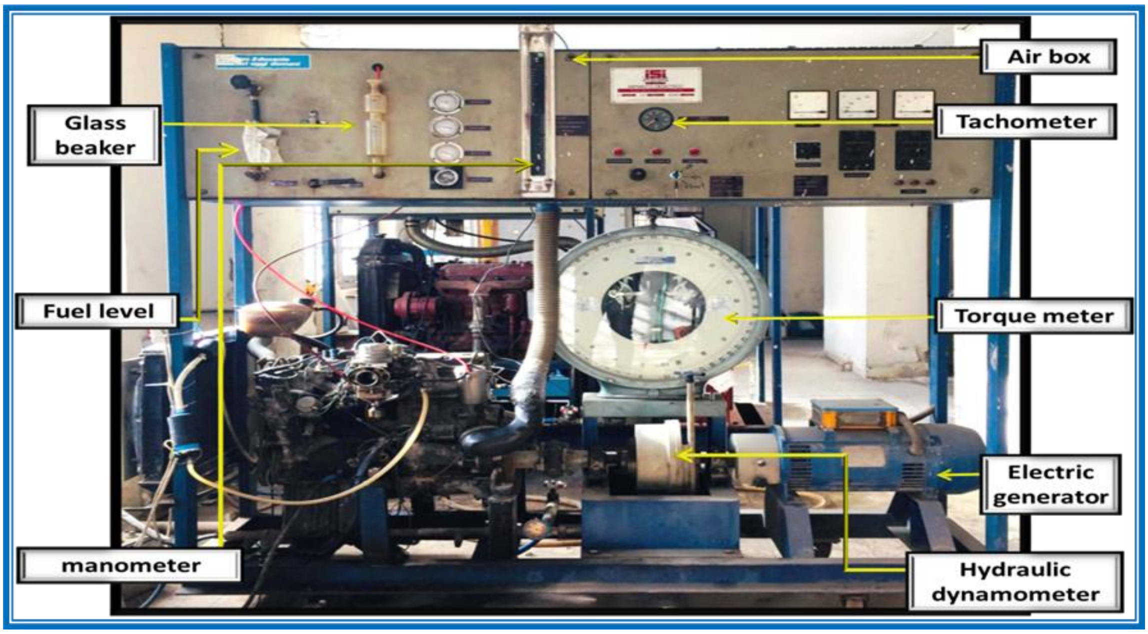


Fig. (1):Experimental test rig.

Table(1):Properties of the fuel used in the tests.

Research Octane number	94.5
Density at 15.60°C (kg/m^3)	739
Average molecular weight	114.8
Heating value (kJ/kg)	41030.64
Carbon (wt.%)	93.12
Hydrogen (wt.%)	13.1
CH composition	$C_{7.76}H_{13.1}$

Table (2): The technical specifications of the used engine.

Engine type	Naturally aspirated petrol
Cylinders	Straight (four-stroke)
Displacement volume	1997cm^3
Bore x Stroke	89 x 80.25(mm)
Connecting rod length	150 (mm)
Compression ratio	9:1
Max. Power @ rpm	80 kW (107.5 hp) @ 5500 rpm
Max. Torque @ rpm	165 N.m (118 lb·) @ 3000 rpm
Fuel System	Carburetor type
Cooling	Water cooling system

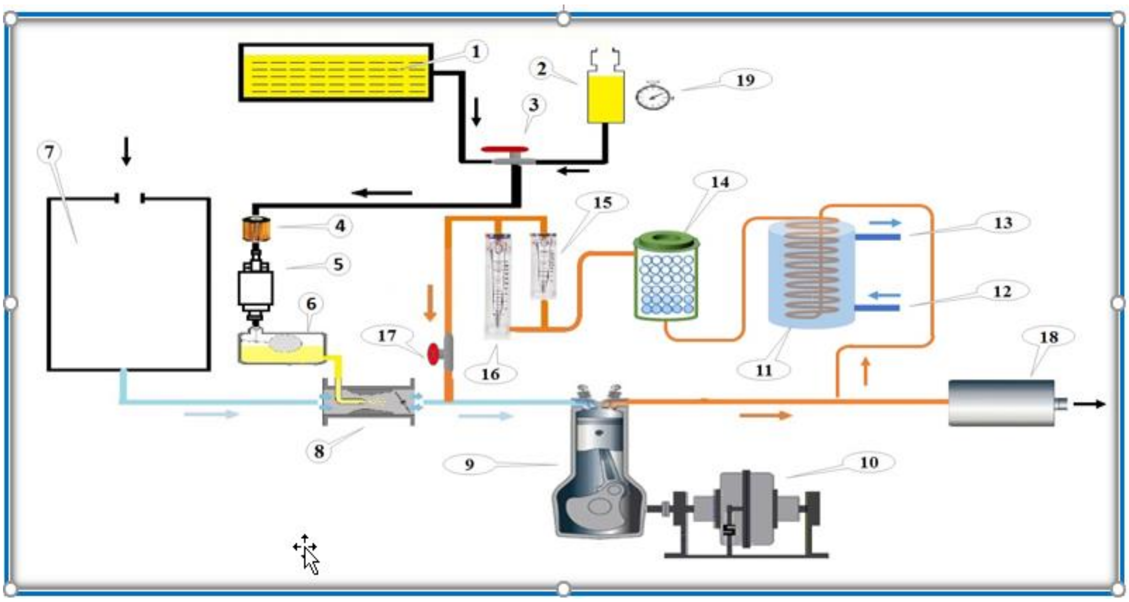
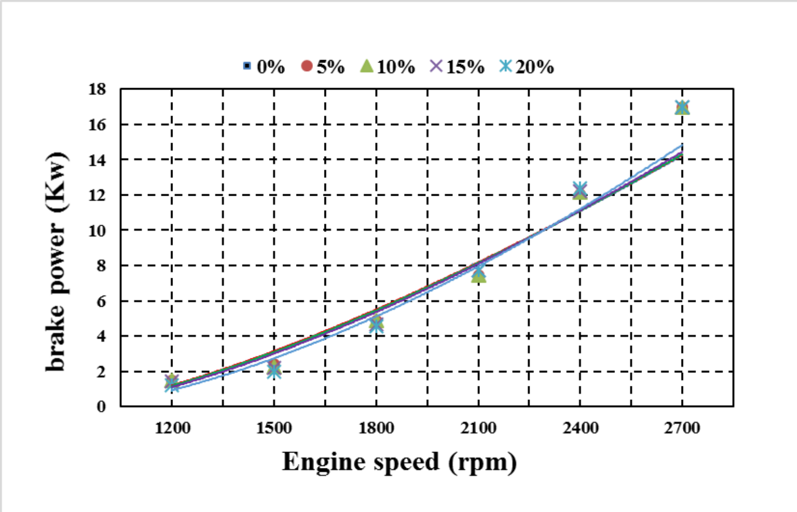
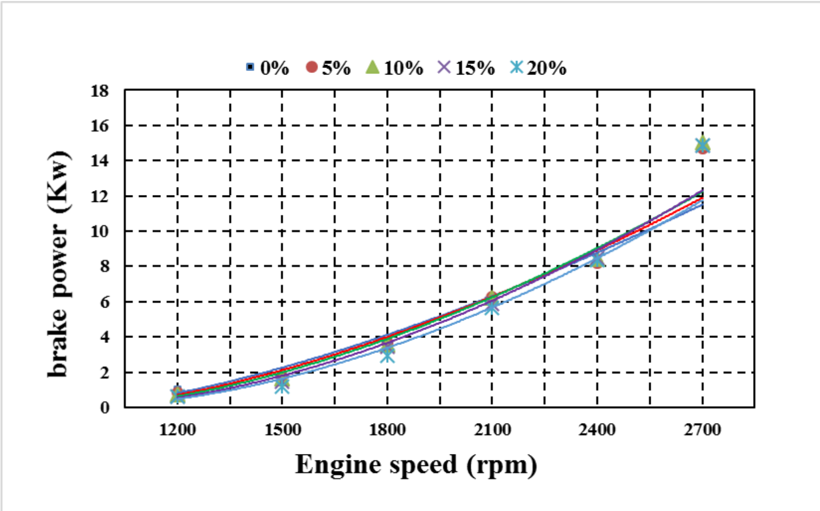


Fig. (2): Schematic diagram of the test rig.

1	Fuel Tank	6	Carburettor Tank	11	Heat Exchanger	16	High Speed Flowmeter
2	Glass Bulb	7	Air Box	12	Inlet Water	17	Control Valve
3	Control Valve	8	Carburettor	13	Outlet Water	18	Muffler
4	Filter	9	SI Engine	14	Air Filter	19	Stop Watch
5	Fuel Pump	10	Hydraulic Dynamometer	15	Low Speed Flowmeter		

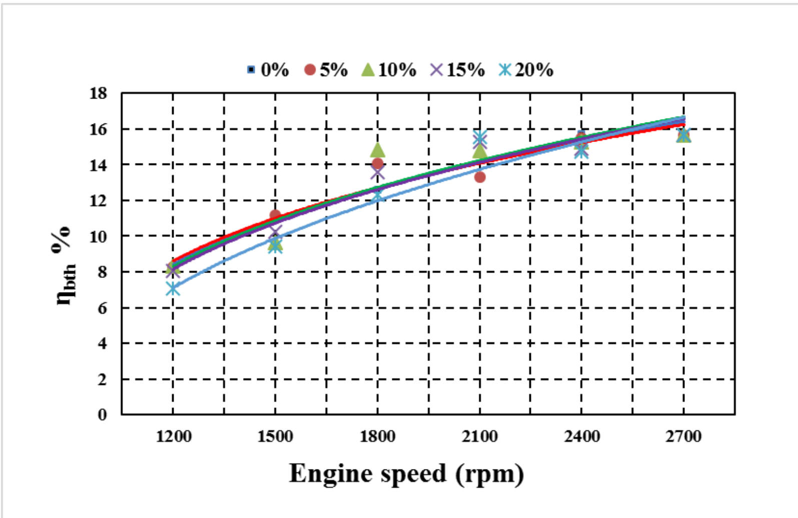


(a) maximum load of RON94.5.

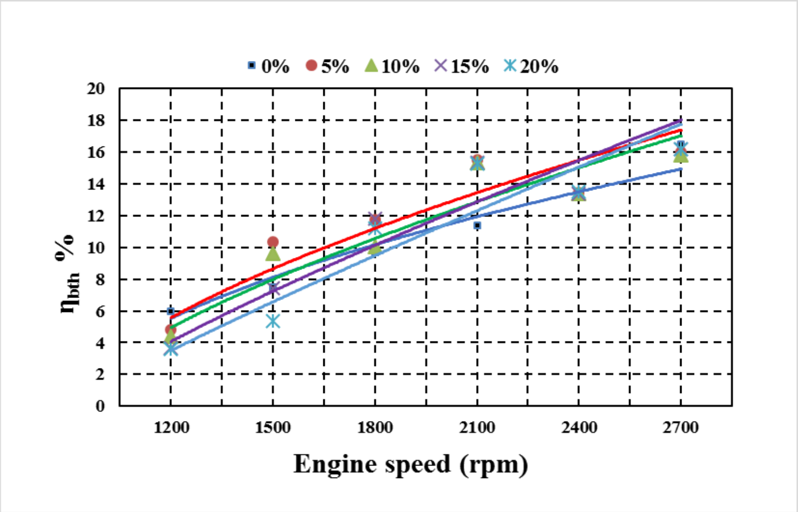


(b)Minimum load of RON94.5.

Fig. (3): Variation of brake power with the engine speed at different EGR ratios

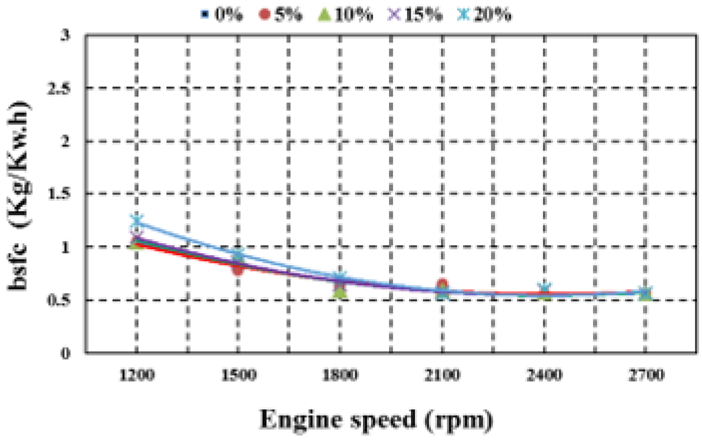


(a)Maximum load of RON94.5

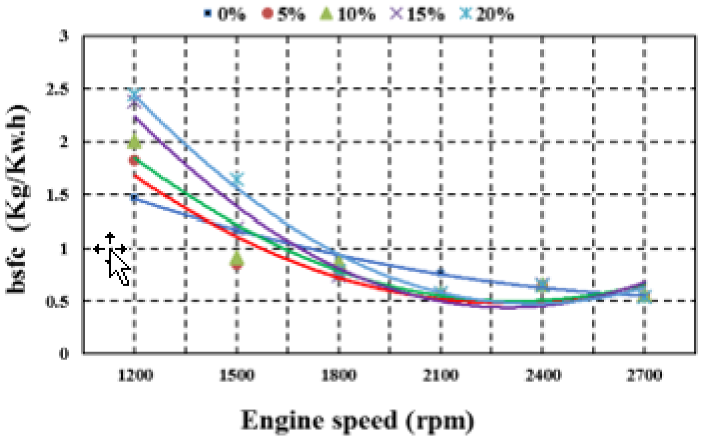


(b)Minimum load of RON94.5.

Fig. (4): Variation of brake thermal efficiency with the engine speed at different EGR ratios

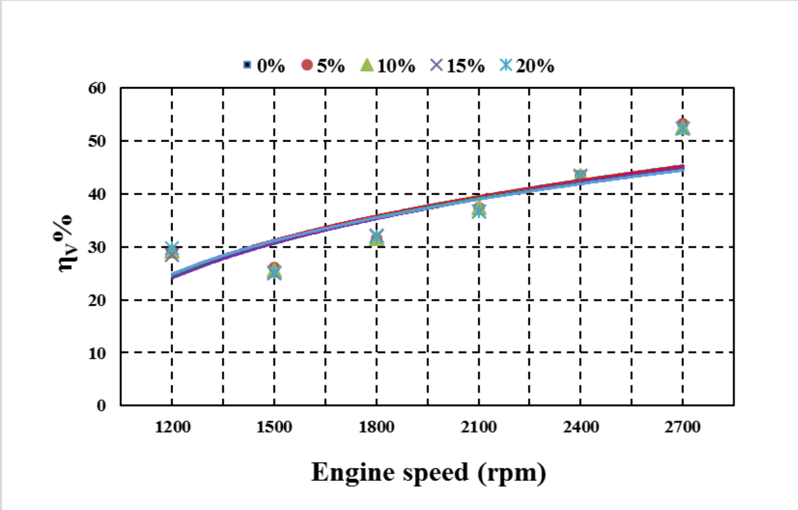


(a)Maximum load of RON94.5

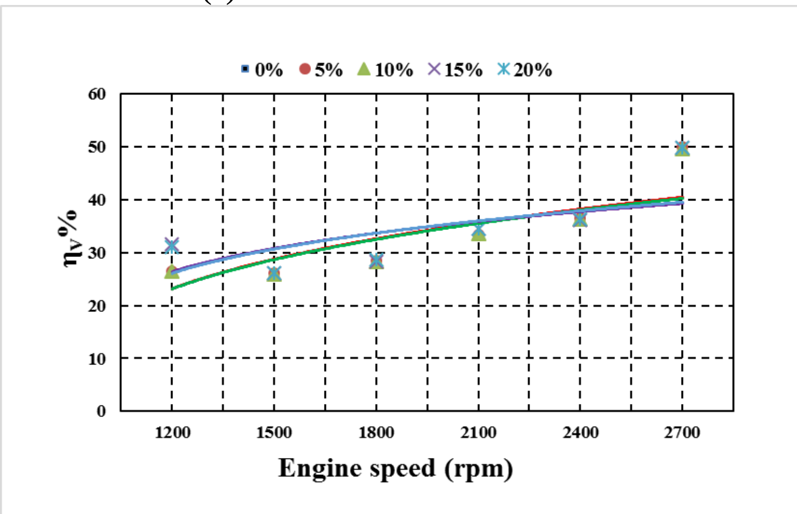


(b)Minimum load of RON94.5.

Fig. (5): Variation of brake specific fuel consumption with the engine speed at different EGR ratios

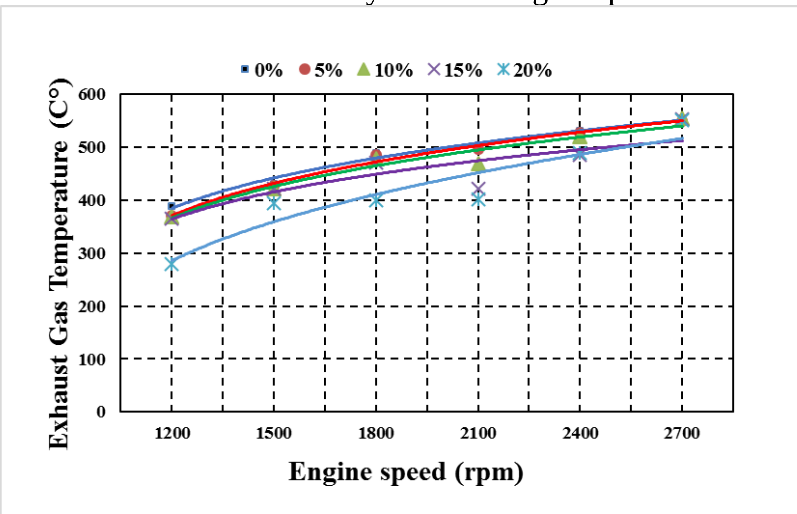


(a)Maximum load of RON94.5

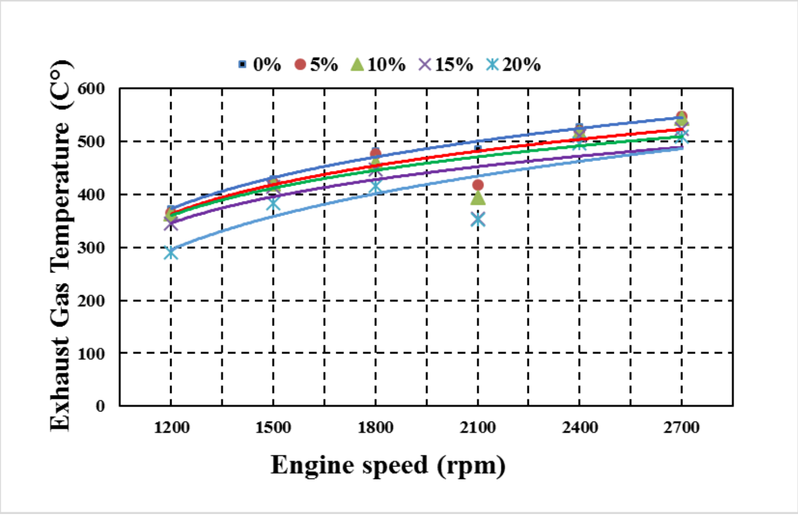


(b)Minimum load of RON94.5.

Fig. (6): Variation of volumetric efficiency with the engine speed at different EGR ratios

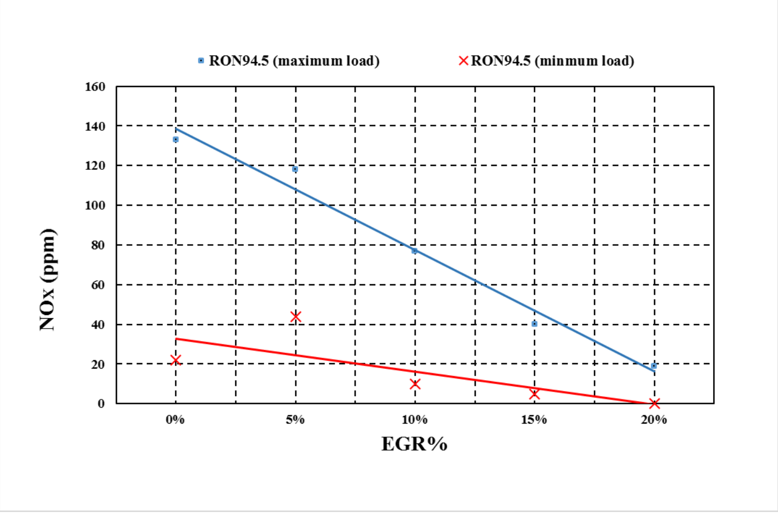


(a)Maximum load of RON94.5

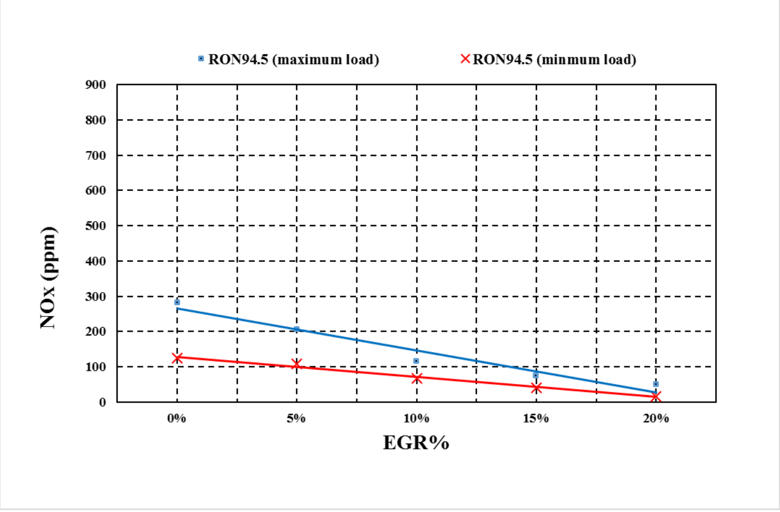


(b)Minimum load of RON94.5.

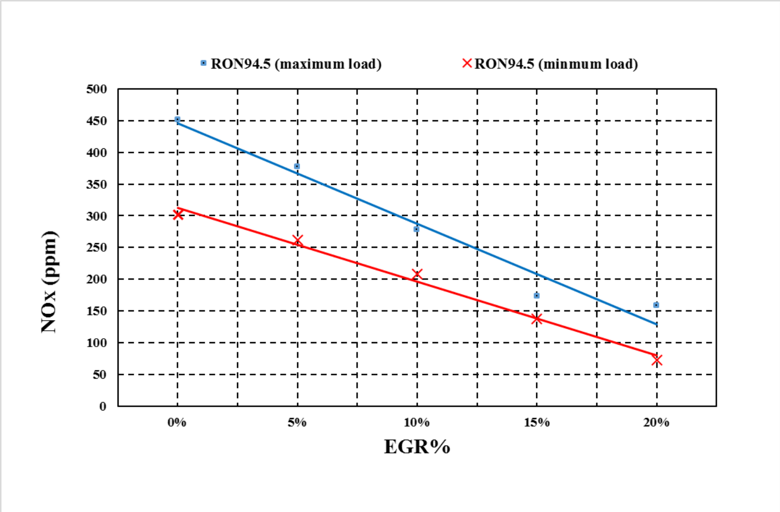
Fig. (7): Variation of exhaust gas temperature with the engine speed at different EGR ratios



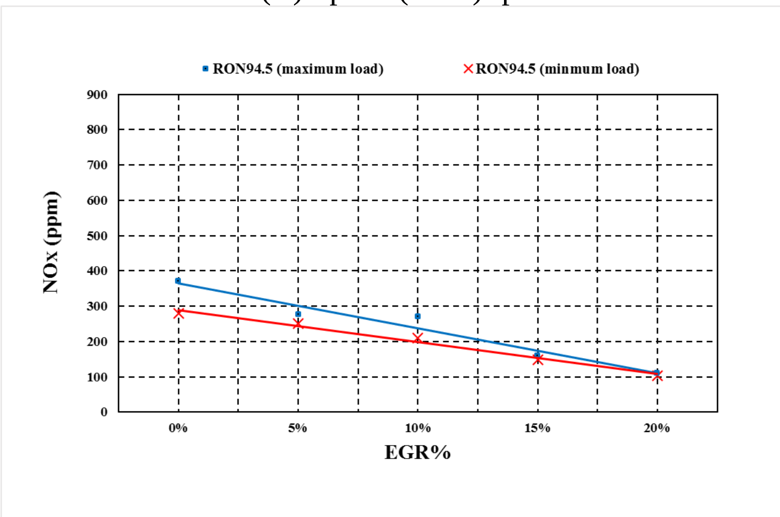
(a)Speed (1200) rpm



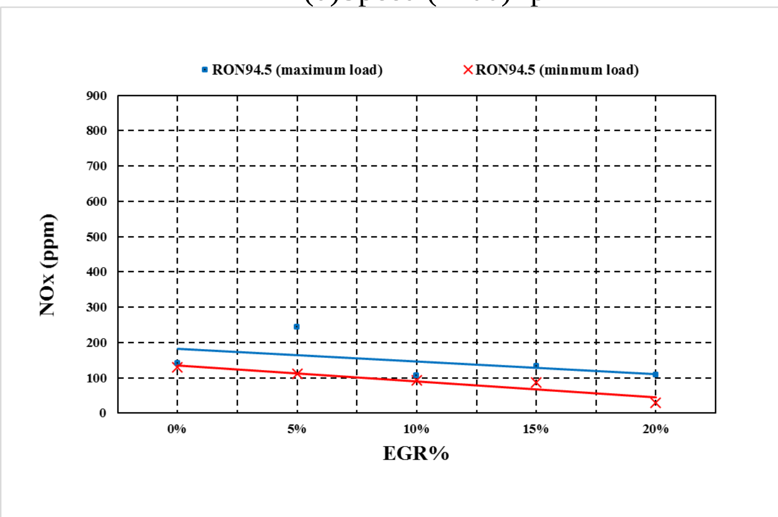
(b) Speed (1500) rpm.



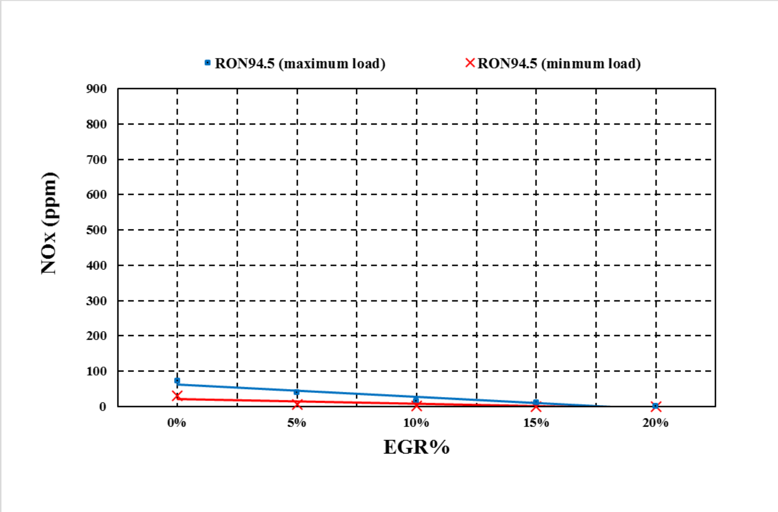
(c) Speed (1800) rpm



(d)Speed (2100) rpm



(e)Speed (2400) rpm.



(f) Speed (2700) rpm

Fig. (8): Variation of NO_X with the EGR ratios for different speeds

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