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Experimental Study of the Effect of Exhaust Gas Recirculation (EGR) and Injection Timing on Emitted Emissions at Idle Period

Miqdam Tariq Chaichan

Department of Machines and Equipments Engineering/ University of Technology

E. mail: miqdam_tc@uotechnology.edu.iq

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Abstract

Heavy-duty diesel vehicle idling consumes fossil fuel and reduces atmospheric quality at idle period, but its restriction cannot simply be proscribed. A comprehensive tailpipe emissions database to describe idling impacts is not yet available. This paper presents a substantial data set that incorporates results from DI multi-cylinders Fiat diesel engine. Idle emissions of CO, hydrocarbon (HC), oxides of nitrogen (NOx), smoke opacity, carbon dioxide (CO_2) and noise have been reported, when three EGR ratios (10, 20 and 30%) were added to suction manifold.

CO_2 concentrations increased with increasing idle time and engine idle speed, but it didn’t show clear effect for IT advancing. CO concentrations increased for all the studied tests with adding EGR. HC concentration increased with idle time advance, but it reduced with increasing idle speed and advancing engine IT. NOx concentrations reduced with adding EGR for all the tested variables. NOx increased with increasing idle time, engine speed and advancing IT. Smoke opacity increased with increasing idle time and retarding IT. Using EGR increased opacity for all tested cases. EGR addition reduced engine noise for all tested cases. Engine noise increased with increasing idle time and retarding IT.

Keywords: *Engine idling, idle time, injection timing, EGR, NOx, PM, HC CO, noise, smoke opacity.*

1. Introduction

Today the diesel engine is the power source with the lowest specific fuel consumption and is essential in the global reduction of carbon dioxide emissions. The success of the diesel engine is due to a precisely controlled combustion process and high technology exhaust after treatment. This combination yields very low fuel consumption combined with the lowest possible emissions. But diesel engines still have some problems especially in cold start, warm-up and idle regions [1 & 2].

In Iraq, diesel engines are used very highly as long-haul trucks, buses, mini buses, trains, constructing machines and electrical generators. Most of these engines typically spend a substantial percentage of time idling while the driver takes mandatory rest periods (i.e., hours of driving and rest, at control and checking points or at traffics). That amount of time varies considerably. Drivers may allow their engines to idle for a variety of reasons and under many different circumstances. Lutsey [3] found climate control to be the most common reason cited by drivers for idling, and use of accessories and concerns about start-up were also cited. On-duty drivers of both long- and short-haul trucks may also tend to idle their engines during the workday while waiting to load or unload or while sitting in traffic, or they may idle their engines for other reasons related to their work or to vehicle operation and maintenance [4 & 5]. Drivers of long-haul trucks often live in these trucks for days, sometimes weeks, at a time as they deliver these goods. When stopped overnight, many of these drivers leave their engines idling to heat or air-condition their cabs and produce power for the amenities they need to carry on their lives while on the road [6 & 7].

Diesel engine idling increases fuel consumption, engine wear, and required engine maintenance. The fuel consumption for diesel trucks at idle is typically 0.8–1.5 g/hr, depending on the engine size, ambient temperature, and load for HVAC and other electrical loads. Idling also causes undesirable emissions. The average emissions for heavy-duty diesel engines are shown in Table 1.

Table 1,
Heavy duty diesel engine emissions at idle (g/hr) [8].

Emission	Heavy Duty Diesel
Voltaic organic compounds (VOC)	12.6
Carbon monoxide (CO)	94.6
Oxides of nitrogen (NOx)	144*
Particulate matters (PM)	2.57
Carbon dioxide (CO_2)	8.224*

Source: Environmental Protection Agency (EPA) web site:
www.epa.gov./OMS/consumer/f98014.htm (April 1998) and
*http://www.epa.gov/otaq/retrofit/decuments/r02025.pdf (October 2002).

Heavy-duty trucks are typically parked and idled so the driver can rest at truck stops and roadside rest areas instead of checking into a motel. These stops can have hundreds of trucks idling in the parking area at once. Diesel-powered trucks at idle produce noise, vibrations, and emissions that affect drivers, other truck stop or rest area patrons, and neighbors [9 & 10].

Long duration idling consumes over one billion gallons of fuel annually in the United States, at a cost of over $2.5 billion [11]. Idling of trucks, alone, is estimated to emit 11 million tons of CO_2, 180,000 tons of nitrogen oxides (NOx), and 5,000 tons of fine PM each year. A single hour of truck engine idling consumes approximately one gallon of fuel and emits approximately 20 pounds of CO_2 [12].

Warming up or cooling down a vehicle is the most common reason given for idling, in the winter and summer. A study of diesel school buses waiting in the wintertime found that restart and immediate departure produced fewer air pollutants compared to idling [13]. The USEPA measured PM, NOx, CO, and PAH from buses under idle and restart conditions and found that for periods longer than three minutes, more pollution was created by idling than by turning buses off and restarting them. In all cases they identify turning off the engine and restarting with immediate departure as a preferred approach [14]. The risks from elevated pollution due to idling extend to passengers as well as to people outside the vehicles. Research shows that school buses self-pollute, meaning that emissions from the bus enter directly into the passenger compartment, even when the windows are closed. These pollutants concentrate more during idling [15 & 16]. Opening the door of the bus after time spent idling, as is often done when buses are waiting to pick up children, can cause a spike in PM concentrations inside the bus [17].

The present investigations aims to measure the effect of idle time accompanied with using EGR and variable injection timings on DI multi-cylinders diesel engine emitted emissions at idle period.

2. Experimental Setup

All experiments were performed with four cylinders DI Fiat engine. The engine was mounted on a test-bed and connected to a hydraulic dynamometer. Power is supplied to the engine control unit, low pressure fuel pump and glow plug by a 12V automotive battery. In this study, the idle rpm was chosen at 1000 rpm to mimic the field observations. The 30-minute continuous idling period was chosen as a compromise emitted emissions. Fig. 1 represents the rig used in recent study. Table 2 illustrates the used engine specifications.

The experimental study is foxed on investigating the effect of tested EGR rates and different injection strategies on engine emitted emissions. Fig. 2 shows the Prodit heat exchanger used as EGR unit. Different combinations are assessed to study the effect of pilot injection strategy on idling period. Two retarded injection timing (15 & 12^{o}BTDC), and two advanced injection timing (20 & 23^{o}BTDC) were used to study the effect of injection timing on engine idle at constant speed 1000 rpm. The results were compared with optimum injection timing (17^{o}BTDC). The effect of variable engine idle speeds (600, 800, 1000 and 1100) were studied at constant IT (17°BTDC).

Table 2,
The tested engine specifications.

Engine type	4cyl., 4-stroke
Engine model	TD 313 Diesel engine rig
Combustion type	DI, water cooled, natural aspirated
Displacement	3.666 L
Valve per cylinder	Two
Bore	100 mm
Stroke	110 mm
Compression ratio	17:1
Fuel injection pump	Unit pump 26 mm diameter plunger
Fuel injection nozzle	Hole nozzle: 10 nozzle holes Nozzle hole dia.= (0.48mm) Spray angle= 160^o Nozzle opening pressure= 40 MPa

Fig. 1. Photographic picture for the experimental rig.

Exhaust gas (smoke) opacity was measured continuously with the AVL 439 partial flow opacimeter, which is particularly suitable for dynamic testing measurements with a response time less than 0.1 s and an accuracy of 0.1 per cent opacity. CO with a non-dispersive infrared (NDIR) analyzer and HCs with a flame-ionization detector (FID) were measured. NOx was measured using a chemiluminescence analyzer. Table 3 represents the equipment, detection principle and accuracy of measuring devices.

All analyzers were calibrated at Science and Technology Ministry of Iraq. Finally, combustion noise was measured with an AVL 450 combustion noise meter.

Fig. 2. EGR assembly used in the present study.

2.1. Experimental Procedure

The experimental schedule included operating engine at different injection timing. Four injection timings and three EGR were studied. It must be highlighted that a preconditioning procedure was followed before most of the tests, in order to remove the deposited particulate matter on the exhaust pipe walls, which could be blown out and released during the following experimental trials. This procedure was followed before the idle operation and the fully warmed-up tests.

2.2. Properties of Tested Fuel

The conventional diesel fuel used was supplied by the Al-Doura Refineries – Baghdad, Iraq and represents the typical, high sulfur (1% by weight) diesel fuel. The fuel properties are given in Table 4.

Table 3,
Summary of equipment, detection principle and accuracy of measurements.

Measuring item	Detection principle	Equipment (Maker)	Scale range	Accuracy
CO	NDIR (non dispersive infrared)	Multigas Mode 4880	0-10% vol.	0.01%
CO_2	NDIR (non dispersive infrared)	Multigas Mode 4880	0-25% vol.	0.01%
HC	FID (Flame ionization detector)	Multigas Mode 4880	0-1000 ppm	0.01%
NOx	CLD (Chemical luminescence detector)	Multigas Mode 4880	0-1000 ppm	0.02%
Overall sound pressure	Precision sound level meter 4615	Italy made	0-200 dB	0.76%
smoke opacity	partial flow opacimeter	AVL 439	0-20 % vol.	0.24%

Table 4,
Diesel fuel used in recent study properties.

Specification	Diesel
Chemical formula	$C_{10.8}H_{18.7}$
Mole weight (g)	148.3
Density (g/cm^3 at 20^{o}C)	0.84
Boiling point (^{o}C)	180-330
Heat of evaporation (kJ/kg)	280
Lower heat value (MJ/kg)	42.5
Liquid viscosity (cP at 20^{o}C)	3.03
Surface tension (mN/m at 20^{o}C)	34.1
Flash point (^{o}C)	78
Stoichiometric air fuel ratio	14.4
Cetane number	45
Auto-ignition (^{o}C)	235
Carbon content (wt%)	87.4
Oxygen content (wt%)	0

2.3. Engine Speed Stability

The idle stability depends strongly on the combustion process. Misfires have a negative effect on the idle stability. During idle application from 600 to 1000 rpm engine speed stability was detected and ensured throughout the whole test.

3. Results and Discussions

Idle emissions from DI multi cylinder Fiat engine was considered in this study. The tests were conducted to measure the engine exhaust emissions to prepare acceptable data for what happening at idle period. Many variables were tested as the following:

3.1. Idling Time Effect

Fig.3 shows the effect of idling time on CO_2 concentrations when the engine runs at optimum injection timing (OIT) and 1000 rpm. Idling time=30 minute was chosen to clarify idle time effect, because this period occurrence is possible in traffics; like stopping in traffic light or in congestion, or as happens in Iraq stopping in control points for frisking. CO_2 increase with increasing idling time to 10-15 min, after that it reduced with increasing time. Increasing CO_2 concentrations means better combustion, while its reduction means poor combustion. CO_2 concentration reduced with increasing EGR rates.

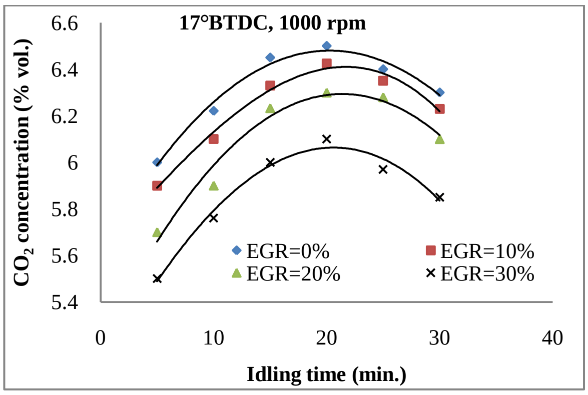

Fig. 3. Idling time effect on CO_2 concentrations for variable EGR rates at OIT and 1000 rpm.

EGR addition will be on air account and will create poor and very rich zones. These zones increase CO and HC concentrations on CO_2 account. The reduction in CO_2 concentration was 1.4, 3.58 and 7.1% for EGR=10, 20 and 30 respectively compared with EGR rate = 0%.

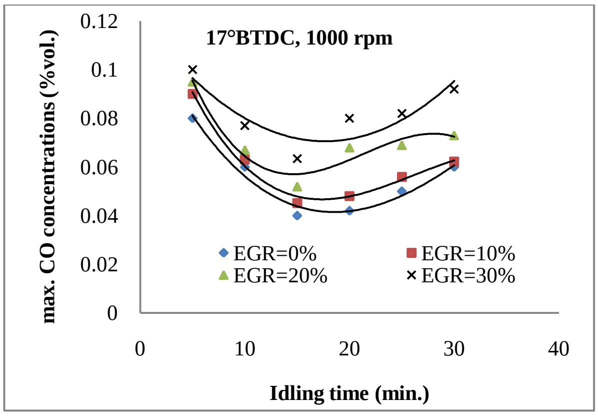

Fig. 4. Idling time effect on CO concentrations for variable EGR rates at OIT and 1000 rpm.

CO emissions are generally low during idling and reduced further with advancing idle time from 0 to 15-20 min, after that it started to increase as Fig. 4 represents. CO reductions confirm the previous results that there is a combustion improvement during this period, due to engine heat improvements.

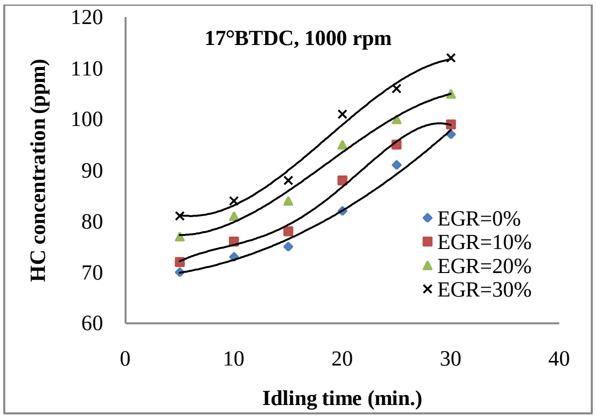

Fig. 5. Idling time effect on HC concentrations for variable EGR rates at OIT and 1000 rpm.

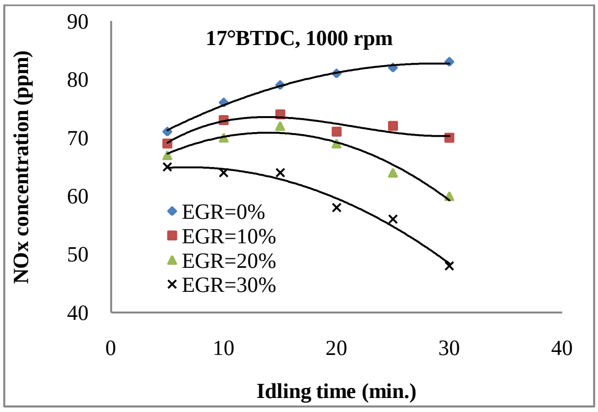

Fig. 6. Idling time effect on NOx concentrations for variable EGR rates at OIT and 1000 rpm.

CO concentrations increased due to combustion deterioration, since continue heating will cause CO_2 to dissociate to CO. Adding EGR increases CO concentration for all rates districting its negative effect on this emission. The increments in CO concentration with EGR addition were 4.33, 27.67 & 53.57% for EGR rates= 10, 20 & 30 respectively compared with adding 0% EGR. Since diesel engines generally have excess oxygen and high combustion temperatures, CO emissions are generally much lower than CO_2 emissions.

A significant amount of HC emissions are developed during the cold start of a diesel engine.

A cold start is significantly below normal operating temperature. HC emissions occur mainly from poor fuel vaporization, which occurs during cold start. For the engine idle tests, data was acquired after the engine is wormed up, which never included any cold start emissions. Increasing idle time increases HC concentrations as Fig. 5 declines. Also, increasing EGR rates added to combustion chamber increased HC concentrations. The increments were 4.09, 11.06 & 17.21% for EGR rates= 10, 20 & 30 respectively compared with adding 0% EGR.

Idling time extension increased NOx concentrations for EGR=0% case, as Fig. 6 reveals. But this extension reduced NOx in the other studied cases. Increasing idle time means increasing heat inside combustion chamber due to reduction in engine cooling abilities. Increasing heat gives higher NOx concentrations as a result. Adding EGR reduces combustion chamber temperature and the heat produced from combustion, this effect causes NOx concentration to reduce. The effect of EGR addition is to reduce NOx and that is its duty. NOx concentration reduced by about 9.11, 14.83 & 24.788% for EGR rates= 10, 20 & 30% respectively compared with EGR=0%.

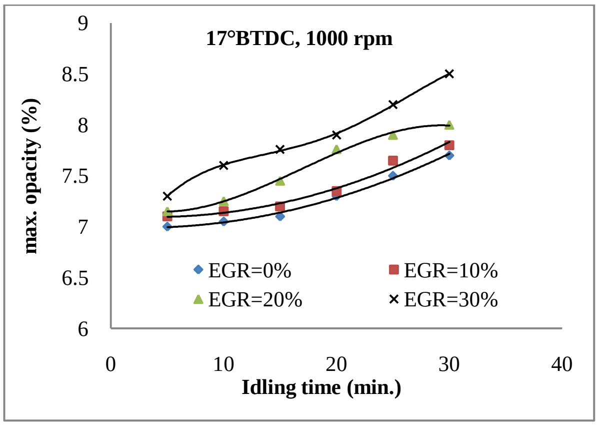

Fig. 7. Idling time effect on smoke opacity for variable EGR rates at OIT and 1000 rpm.

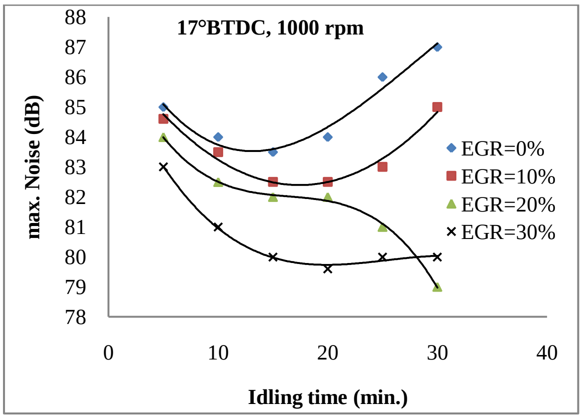

Fig. 8. Idling time effect on engine noise for variable EGR rates at OIT and 1000 rpm.

Low combustion temperatures and non-stoichiometric oxygen conditions result in incompletely burned fuel, and various concentrations of particulates largely of carbon composition. Engine emitted these fine particulates consisted of elemental carbon (EC), organic carbon (OC), metals from fuel and engines wear, and sulfates with bound water. EGR effect on smoke opacity conflict with its effect on NOx, as Fig. 7 represents. Increasing EGR rates increased smoke opacity, as well as increasing idling time increased opacity. Opacity reduction needs high temperatures to reduce smoke, while adding EGR reduces these temperatures causing increment in opacity. Increasing idling time increases heat slightly inside combustion chamber. But it also increases heterogeneous zones which causes many rich zones produces higher opacity. For 0% EGR the increment in opacity because of increasing idling time was 10%. The increment in smoke opacity was 1.37, 4.26 & 8.27 for EGR rates=10, 20 & 30% respectively compared to 0% EGR.

Engine noise reduced slightly with increasing idle time from zero to 10 minutes, but it return to increase after that with engine idle continuing, as Fig. 8 clarifies. Adding EGR reduces engine noise due to the relation between pressure rates inside combustion chamber and noise. EGR addition reduces combustion efficiency and pressure rates as a result engine noise reduced. The reduction in engine noise was 2, 3.72 & 5.08% for EGR rates =10, 20 & 30% compared to 0% EGR.

3.2. Engine Speed Effect

Experiments were conducted on the engine to measure CO, CO_2, NOx, HC, opacity during idling conditions. Period of 30 min. was used as idling time and injection timing was fixed at optimum injection timing.

CO_2 emissions are a direct function of fuel consumption. During combustion, the products from the carbon in the fuel are CO_2, and the byproducts are CO, HC, and formaldehydes. The majority of the carbon products are formed into CO_2, so as more fuel is consumed like by increasing engine idle speed, CO_2 concentrations increase, as Fig. 9 reveals.

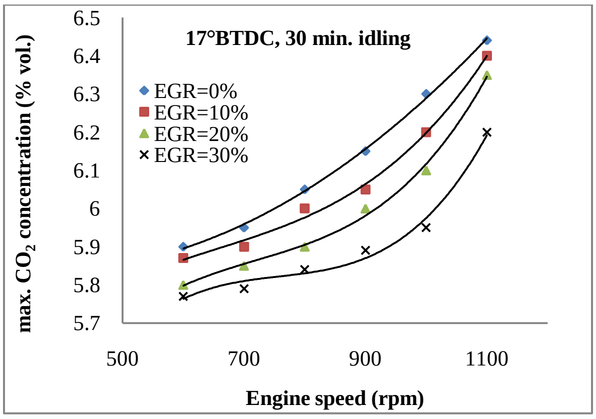

Fig. 9. Engine speed effect on CO_2 concentrations for variable EGR rates at OIT for 30 min idling run.

CO_2 concentrations increased about 9.15% with increasing idle speed from 600 to 1000 rpm. Adding EGR reduced these concentrations for the tested range. Increasing engine speed increases air and heat inside combustion chamber resulting in better combustion. Better combustion means higher CO_2 concentrations.

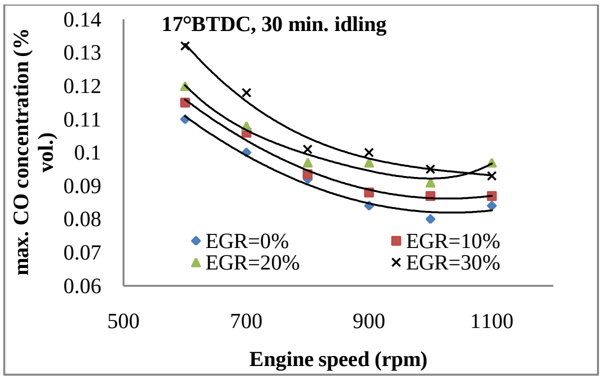

Fig. 10. Engine speed effect on CO concentrations for variable EGR rates at OIT for 30 min idling run.

CO concentrations behave in the opposite of CO_2, as Fig. 10 manifests. Increasing idle speed reduced CO concentrations with about 23.63%. While increasing EGR rates increased CO concentration, for the same reason mentioned previously. The increments were 4.8, 10.9 & 16.18% for EGR=10, 20 & 30% respectively compared to 0% EGR.

Fig. 11 shows idle engine speed effect on HC concentrations for several EGR rates. HC concentrations behave as CO concentrations for same reasons. It reduced with increasing engine idle speed with about 24.28%. While it increased with increasing EGR rates. Increments were 3.24, 5.67 & 10.27% for EGR=10, 20 & 30% respectively compared to 0% EGR.

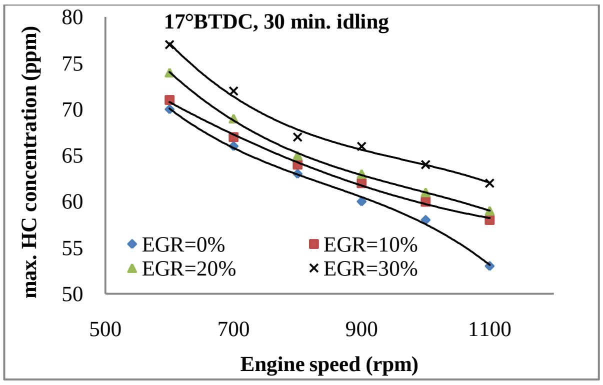

Fig. 11. Engine speed effect on HC concentrations for variable EGR rates at OIT for 30 min idling run.

EGR duty is to reduce NOx and that what Fig. 12 demonstrates. NOx concentrations reduced with increasing EGR rates, and it reduced even more with increasing idle speed on the contrary of 0% EGR case. In the normal case increasing idle speed means increasing air and heat inside combustion timing with available time for formation (where idle speeds can be considered low speeds).

In this case, increasing EGR rates improved its effect with time (it must be put in mind those measuring max. concentrations after the engine idling for half an hour). Low speed idling made many rich zones in combustion chamber which produced local high temperatures even with EGR addition due to reduction in turbulence inside combustion chamber. The reduction in concentrations were 3.63, 9.44 & 13.55% for EGR rates= 10, 20 & 30% respectively compared with EGR=0%.

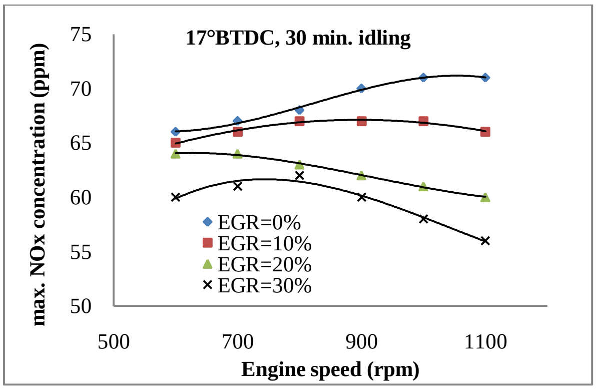

Fig. 12. Engine speed effect on NOx concentrations for variable EGR rates at OIT for 30 min idling run.

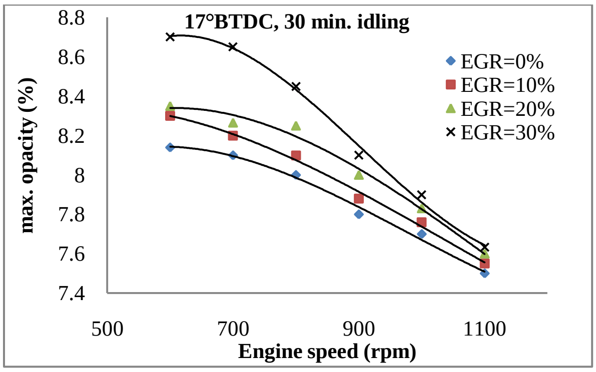

Fig. 13. Engine speed effect on smoke opacity for variable EGR rates at OIT for 30 min idling run.

Smoke opacity reduced with increasing idle speed, but it increased with EGR addition, as Fig. 13 demonstrates. Increasing engine speed (from very low speed as 600 rpm to moderate speed as 1100 rpm) increases combustion efficiency and reduces opacity. EGR effect resists this effect, but the available results indicate that increasing combustion efficiency overcomes EGR effect. Opacity increments were 1.16, 2.23 & 4.64% for EGR rates=10, 20 & 30% respectively compared to 0% EGR.

Engine noise increased with adding EGR at low speeds and reduced for higher speeds compared with no EGR addition, as Fig. 14 represents. At low idle speeds engine vibration increased highly causing high noise rate, while at higher idle speeds large reduction in engine vibration achieved causing lower noise. Adding EGR in good combustion conditions results in reduction in engine noise, arising from reduction in pressure combustion rates accompanied with this addition.

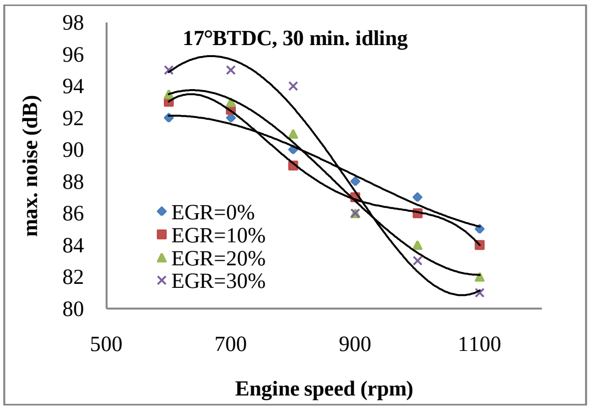

Fig. 14. Engine speed effect on engine noise for variable EGR rates at OIT for 30 min idling run.

3.3. Injection Timing Effect

CO_2 concentrations reduced with retarding injection timing from OIT highly, and it reduced slightly with advancing IT also, as Fig. 15 reveals. Retarding IT causes late combustion which means part of it will be in the expansion stroke; result in less power and lower exhaust temperatures. These factors causes bad combustion which produces low CO_2 concentration, associated with higher CO and HC concentrations (Figs. 16 & 17) at these IT. Advancing IT increases pressure rates and heat produced inside combustion chamber resulting in better combustion. This combustion improvement doesn't affect CO_2 while it reduces CO and HC concentration highly as Figs 15, 16 & 17 represent.

Retarding injection timing was considered one of the treatments can be used to reduce NOx concentrations. EGR addition with retarding IT together caused lower NOx concentration, as Fig. 18 reveals. Contrary to opacity which increased highly with these two factors accompanied as Fig. 19 represents. The conditions reversed at advancing IT, where heat and available time increased generating more NOx concentrations. In this region two conflicting factors applied and EGR addition still reducing NOX (Fig. 18) and increases opacity (Fig. 19).

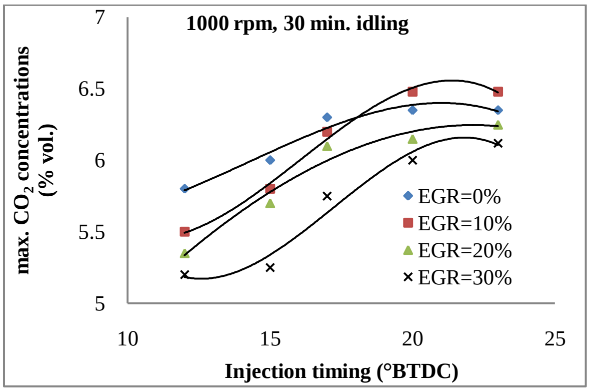

Fig. 15. Injection timing effect on CO_2 concentrations for variable EGR rates at OIT for 30 min idling run.

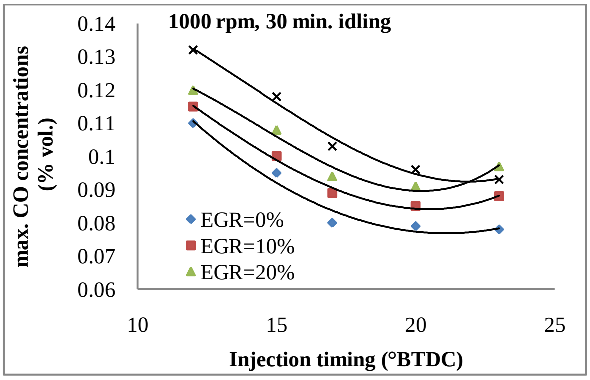

Fig. 16. Injection timing effect on CO concentrations for variable EGR rates at OIT for 30 min idling run.

Engine noise increased highly with EGR addition and IT retarding, as Fig. 20 shows. Retarding engine IT increased engine vibration, while adding EGR made combustion more difficult, and the result higher engine noise. In contrast to the former mentioned, adding EGR with advanced IT reduced noise. Advancing IT increases produced pressure rates from combustion witch increases noise, while adding EGR reduces noise. The resultant from applying these two factors clarifies that EGR effect is dominant, as the figure insures.

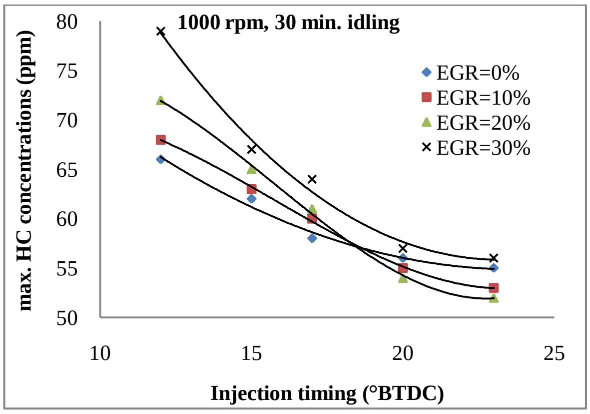

Fig. 17. Injection timing effect on HC concentrations for variable EGR rates at OIT for 30 min idling run.

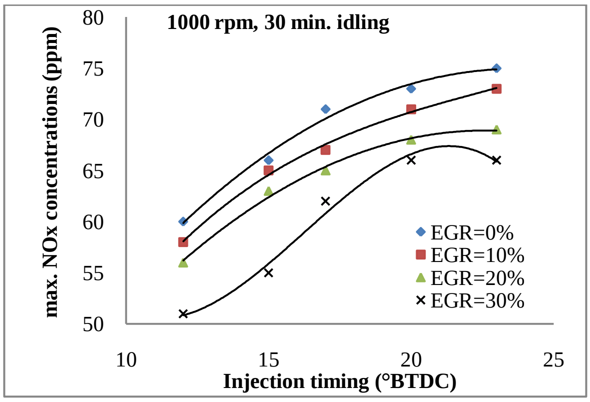

Fig. 18. Injection timing effect on NOx concentrations for variable EGR rates at OIT for 30 min idling run.

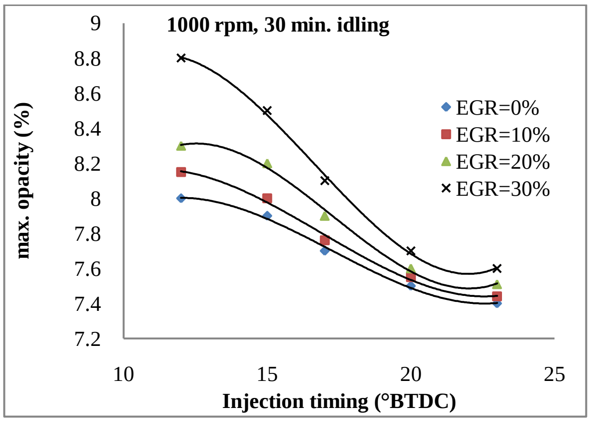

Fig. 19. Injection timing effect on smoke opacity for variable EGR rates at OIT for 30 min idling run.

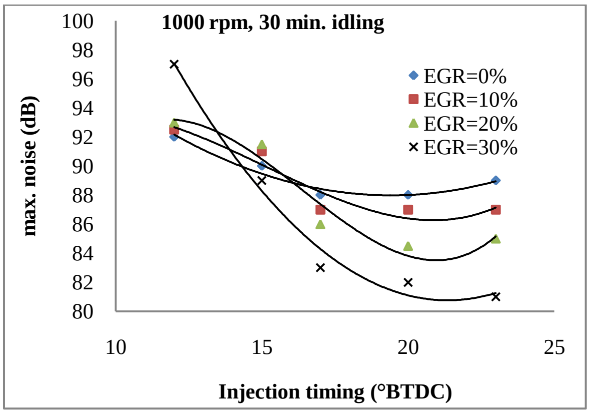

Fig. 20. Injection timing effect on engine noise for variable EGR rates at OIT for 30 min idling run.

3.4. Comparison with Other Studies

It is difficult to compare results of recent study with other similar ones, due to variable tests procedures and measurements. In Fig. 21 a comparison of NOx concentrations for three similar studies at engine speed 600 rpm and variable injection timing for each study. EGR=20% results for recent study was chosen for this comparison depending on several studies like References 18 and 19 which confirm that using 20% EGR gives the best results in reducing NOx with limited effect on brake specific fuel consumption and thermal efficiency. Brodrick [20] showed that NOx concentrations reached its minimum values for idle period of 10-15 minutes after that it increased highly. Hearne [21] results are similar to recent study except for the values at 5 min. which is high due to the measuring procedure for school bus and no EGR employing. Khan [22] studied several cars models and its effects on emissions at idle period. The study focused on models from 1965 to 2005. The average as it seemed in the figure high compared with recent study because EGR was not used in the tested engine. Finally, all results indicate high and hazard NOx concentrations at idle time.

4. Conclusions

Although the small data set reported here improves our knowledge of engine idle emissions, a number of important questions remain unanswered. Data from many more engines from a broader range of manufacturers and using years and maintenance quality are necessary for accurate emissions factors that can be used in air quality modeling. This study insures the need for quick action from Iraqi government and civil society enterprises to educate Iraqi drivers about long idling time risks from economic and health point of view.

Idle emissions of CO, HC, NOx, smoke, noise and CO_2 at idle have been presented in this paper. Three variables were used to test engine emissions when idling with EGR addition in several rates. The tested variables were idling time, engine speed variation and injection timing variation. The results indicate that:

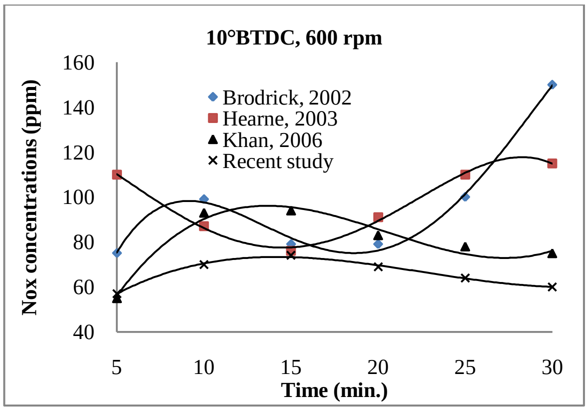

Fig. 21. Comparison of recent study with other similar studies.

- CO_2 concentrations increased with increasing idle time and engine speed, but it didn't show clear effect for IT advancing. In contrast, retarding IT reduced these concentrations. Operating the engine with EGR addition caused a reduction for CO_2 concentration through idle time, increasing engine speed and with IT variation.
- CO concentrations reduced in the first 10 min. of the engine idling period, and then it increased if this period continued. CO reduced with increasing engine speed and advancing IT. Adding EGR increased CO for all the studied tests.
- HC concentration increased with idle time advance, but it reduced with increasing idle speed and advancing engine IT. Adding EGR increased HC for all the studied tests.
- NOx concentrations reduced with adding EGR for all the tested variables. NOx concentrations increased with increasing idle time, engine speed and advancing IT.
- Smoke opacity increased with increasing idle time and retarding IT. While it reduced with increasing engine speed and advancing IT. Using EGR increased opacity for all tested cases.
- EGR addition reduced engine noise for all tested cases. Engine noise increased with increasing idle time and retarding IT. Noise reduced with increasing idle speed and advancing IT.

Notation

BTDC	Before top dead centre
CO	carbon monoxide
CO_2	carbon dioxide
dB	Decibel
EGR	Exhaust gas recirculation
HC	unburnt hydrocarbon
IT	Injection timing
NOx	nitrogen oxides
PM	particulate matters
SO	smoke opacity

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دراسة عملية لتأثير تدوير الغاز العادم (EGR) وتوقيت الحقن على الملوثات المنبعثة خلال فترة الحياد

مقدام طارق جيجان
قسم هندسة المكائن والمعدات/ الجامعة التكنولوجية
البريد الألكتروني: miqdam_tc@uotechnology.edu.iq

الخلاصة

تستهلك سيارات الديزل للخدمة الثقيلة الوقود وتقلل من نوعية الجو خلال مدة الحياد، والى الآن لم يتم تقييد هذة الفترة بقوانين ملزمة. تقدم هذة الدراسة معلومات شاملة مرتبطة بنتائج عملية تمت على محرك ديزل ذي حقن مباشر متعدد الأسطوانات . إذ درست ملوثات الحياد لأول ا وكسيد الكاربون (CO) والهيدروكاربونات غير المحترقة (HC) وأكاسيد النيتروجين (NOx) وعتومة الدخان وثاني اوكسيد الكاربون (CO_2) والضوضاء، عند اضافة ثلاث نسب مختلفة من الغاز العادم المدور الى مشعب الدخول.

تزداد تراكيز CO_2 بزيادة زمن الحياد وسرعة الحياد للمحرك، لكنها لم تظهر تأثيرا واضحا لتقديم توقيت الحقن. وتزداد تراكيز CO لكل الأختبارات باضافة غاز عادم مدور (EGR)، كما زادت تراكيز HC بتقدم توقيت الحياد، ولكنها قلت بزيادة سرعة الحياد وتقديم توقيت الحقن . تقل تراكيز NOx باضافة غاز عادم مدور EGR ولكل المتغيرات المدروسة، وتزداد هذ ه التراكيز بزيادة زمن الحياد وسرعة المحرك وتقديم توقيت الحقن . وتزداد عتومة الدخان بزيادة زمن الحياد وتأخير توقيت الحقن، وباستخدام EGR زادت عتومة الدخان لكل الحالات المدروسة . تقلل اضافة EGR ضوضاء المحرك لكل الحالات المختبرة، وتزداد الضوضاء بزيادة زمن الحياد وتأخير توقيت الحقن.