Operational Parameters Influence on Resulted Noise of Multi-Cylinders Engine Runs on Dual Fuels Mode

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Abstract: *Noise is a pollutant by the combustion process that may have direct effect upon surrounding environment. In this study, noise measurements were taken for multi cylinders, four stroke Fiat engine converted to run as dual fuel engine on diesel and gaseous fuels of liquefied petroleum gas (LPG) and natural gas (NG).*

The study focused on the influence of some operating parameters. These parameters included: engine load, pilot fuel injection timing, pilot fuel mass, and engine speed. It was found that using LPG as the main fuel in duel fuel mixture exhibits higher engine noise compared to NG or neat diesel. The results showed *that advancing injection timing from optimum ones increased engine sound pressure levels.*

Keywords: duel-engine, LPG, NG, noise, injection timing, pilot fuel mass, engine speed.

1. Introduction

In contrast to spark-ignition engines the combustion of diesel engine is regarded as being very regular and stable. This is confirmed by observations of the cylinder pressure signal on an oscilloscope. However, it has been shown that a detailed analysis of the diesel combustion process reveals significant variations from cycle to cycle resulting in combustion noise variations [1].

Noise is a pollutant by the combustion process that may have direct effect upon surrounding environment. It may cause immediate annoyance and physiological change [2]. Combustion noise occurs in two forms, direct and indirect. Direct noise is noise generated in and radiated from a region undergoing turbulent combustion. This is caused by a temporal fluctuation in the aggregate heat release of the reacting region. This overall fluctuation, while small, exists and generates pressure waves. The indirect noise is generated downstream of the combustion region due to interactions between streamlines of different temperatures. Depending on the device, either direct or indirect noise may be dominant. Noise is transmitted throughout the engine block as vibration, which can cause audible noise to the human ear at a different spectrum of frequencies [3 & 4].

Other than airflow and mechanical noise, combustion noise is known to be a main source of noise. This is particularly true for engines that use high compression ratios and the combustion pressure rise is fast. One of the main factors that are known to affect the combustion noise is the pressure rise rate during combustion. It has also been shown that the maximum rate of pressure rise is directly proportional to the sound pressure level in decibels observed in the main chamber of the diesel engine [5 & 6].

Considerable efforts have been applied to have smoother and less noisy diesel engines, and works have been published in relating the diesel engine combustion noise to the engine operating and design parameters [7 & 8]. However, the combustion noise data for the dual fuel engine that utilizes diesel as pilot fuel and gaseous fuel is lacking [9 & 10]. Therefore, it was considered necessary to research the resulted noise of the dual fuel engine that was not covered before. In the present study an attempt is made to relate the combustion noise to the operating parameters for the dual fuel engine as compared to a 100% diesel case. The noise levels are measured and analyzed at different engine loads, engine crankshaft speeds, pilot injection angle, and different pilot mass quantity. The noise data is also compared, at the same conditions, with the diesel engine noise.

This work aims to evaluate the effects of duel fuel mode operation on engine noise levels at variable engine parameters. Conventional Iraqi produced gases (LPG & NG) were used in this study to provide improved knowledge of the combustion phenomena in gas fueled internal combustion engines.

2. Experimental Setup

Experimental apparatus of engine under study is direct injection (DI), water cooled four cylinders, in-line, natural aspirated Fiat diesel engine whose major specifications are shown in Table 1. The engine was coupled to a hydraulic dynamometer through which load was applied by increasing the torque. The cylinder pressure was obtained by a Kistler piezoelectric sensor type 6125A, the output of the pressure transducer was amplified by a Kistler charge amplifier type 5015A (Yokogawa: GP-IB). The schematic diagram for the engine test rig is shown in Fig. 1.

Table 1, 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
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

The engine is converted to run on dual fuel by introducing the gaseous fuel, LPG and NG in the present work, in the intake manifold by a simple, low cost air-gas mixing device, designed as shown in Fig. 2, was used to mix LPG or NG with inlet air during suction stroke. The gas is introduced at a pressure slightly higher than atmospheric pressure. Fig. 3 shows a photographic picture of the testing rig.

In this work the diesel fuel used was Iraqi Al-Doura refinery production with cetane No. 49.6, the LPG fuel produced from Al-Taji Gas Company; consist of ethane 0.8%, 11.47 isobutane, 62.8% propane and 24.45% butane. NG used was produced from Iraqi Northern Gas Company; consist of 88.23% methane, 9.21% ethane, 2.15% propane, 0.15% isobutane, 0.17% n. butane and 0.03% pentane.

The engine is equipped for measurements of the operating parameters and combustion noise data. The liquid fuel flow rate is measured by recording the time required for 200ml of fuel to be consumed. The gaseous fuel flow rate is measured by using an orifice meter connected to electronic partial pressure transducer that is connected to a digital pressure meter. Overall sound pressure was measured by precision sound level meter supplied with microphone type 4615, as appears in Fig. 4; the devise was calibrated by slandered calibrator type pisto phone 4220.

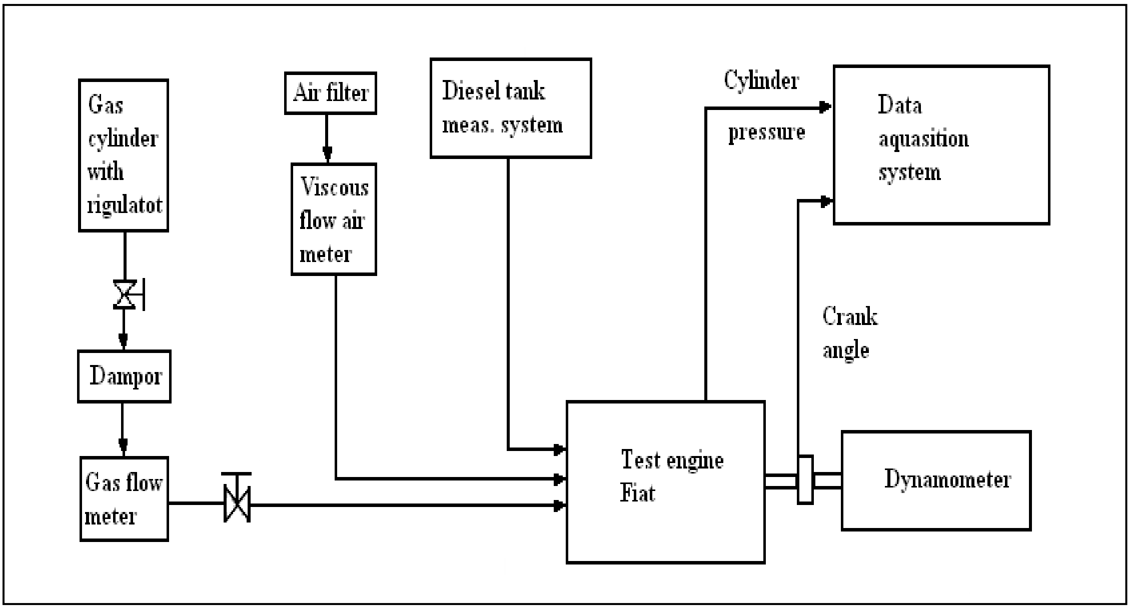

Fig. 1, Schematic Diagram for the Engine Test Rig

Experiments have been carried out after running the engine for some time until it reaches steady state and oil temperature is at 70°C, and cooling water temperature is at 80°C.

Combustion pressure cyclic data is presented for diesel and dual fuel (using LPG or NG as main fuel independently) against the tested engine operating parameters. The engine operating parameters have been varied at the following levels:

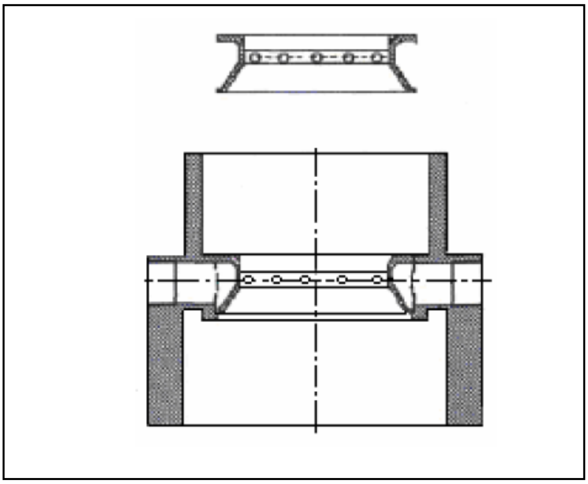

Fig. 2 The Cross Sectional Drawing of the Mixer

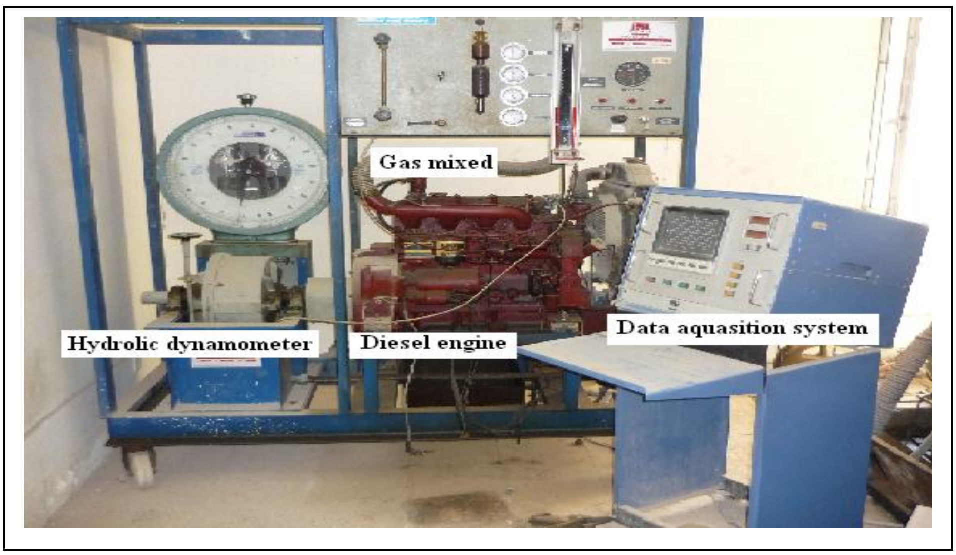

Fig. 3 Photographic Picture of the Testing Rig

1) Type of fuel included pure diesel fuel (base case as normal diesel engine), dual fuel of diesel + LPG or NG.
2) The engine load was varied from 0.5 to 80 N m.
3) The pilot diesel fuel injection timing was varied from 20 to 45^o BTDC in steps of 5^o.
4) The pilot diesel fuel relative mass m_d (at constant mass of gaseous fuel admitted, m_g) from (m_d/m_d+m_g) of 18–42%.
5) The engine speed was varied from 1000 to 2500 rpm.

The experimental error is evaluated according to reference [11]. The maximum uncertainty in any quantity is calculated as the error divided by the average reading of the quantity. The maximum uncertainties in engine speed, torque, diesel proportion (md/md+mg) are 2.5, 3.35 and 2.76%, respectively. The combustion pressure has been measured by the piezoelectric pressure transducer and then converted as pressure from the calibration data.

Fig. 4, Overall Sound Pressure Used In Tests

The microphone was located at a height equal to that of the exhaust outlets of the engine being measured and 1.5 meters from the centre of the measurement lane. In practice the actual location will vary from this and the lab walls. The nominal axis of maximum sensitivity of the microphone was directed towards and perpendicular to the engine. It was supported by a device not providing excessive acoustic reflection. In all cases the position, direction and mounting arrangement of the microphone was recorded.

The purpose of this work is to focus on the attention of the combustion noise for the dual fuel engine, particularly on the phenomenon of combustion noise variations. The effects of some operational parameters were studied. These parameters were the duel fuel type, engine speed, and pilot fuel injection timing and pilot fuel mass percentage in the fuel.

The following equations were used in calculating engine performance parameters:

1. Brake power

$$bp = \frac{2\pi * N * T}{60 * 1000} \quad kW$$

2. Brake mean effective pressure

$$bmep = bp \times \frac{2 * 60}{V_{sn} * N} \quad kN/m^2$$

3. Fuel mass flow rate

$$\dot{m}_f = \frac{v_f \times 10^{-6}}{1000} \times \frac{\rho_f}{time} \quad {}^{kg}/_{sec}$$

4. Air mass flow rate

$$\dot{m}_{a,act.} = \frac{12\sqrt{h_o * 0.85}}{3600} \times \rho_{air} \quad \frac{kg}{sec}$$

$$\dot{m}_{a_{theo.}} = V_{s.n} \times \frac{N}{60 * 2} \times \rho_{air} \quad \frac{kg}{sec}$$

3. Results and Discussion

Effects of torque and fuel type

The effects of fuel type on engine noise data is illustrated in Fig. 5, for the three fuels used: pure diesel fuel as single fuel case, dual fuel using LPG as main fuel, and dual fuel using NG as main fuel. These results are taken at constant engine parameters of 1500 rpm and optimum injection timing (OIT).

The figure shows the variation of noise levels with the load for the three fuels. The load is found to increase the noise level for the single fuel diesel engine as well as the dual fuel cases using either LPG or NG. However, it may be noticed that the noise level is highest for LPG than that for NG, and then the pure diesel fuel gives the lowest value. It is clear that LPG combustion produces the highest maximum pressure followed by NG then diesel fuel.

It has been shown by reference [12] that the ignition delay period of propane (the main constituent of LPG)–diesel–air mixture is longer than methane (the main constituent of NG)–diesel–air mixture and this is longer than the value for pure diesel–air mixture. When propane is used in dual fuel engine it exhibited longer delay than methane and diesel due to the differences in the associated changes in temperatures during compression, changes in preignition energy release, external heat transfer to the surroundings and the contribution of residual gases.

For diesel engine running on diesel fuel the noise level is decreasing with load (or increasing the mass of fuel injected) while it increases with load for the gaseous fuels. This implies that for diesel engine, on increasing the load the mass of fuel injected become bigger and the flame may become bigger and propagate smoother. While for dual fuel engine with gaseous fuels as main fuel, increasing the load means increasing the mass of gaseous fuel while keeping the mass of diesel pilot fuel constant. The increase in the mass of gaseous fuel caused a variation in the gas– air mixture distribution especially at the start of ignition.

Effect of engine speed

The effect of engine speed on combustion noise is depicted in Figs. 6 to 9 for dual fuel and diesel engines running at different speeds. Generally, as the engine speed increases, the combustion pressure rise for most of the output loads.

It has been concluded by Moffat [11] that increasing the engine speed has resulted in a decrease in the ignition delay period of the dual fuel mixture which results in a decrease in the pressure rise rate as a result the noise levels were reduced. It has also been shown by Imoto [7] that the combustion noise decreased when the engine speed increases.

In this study, the pressure rise rate in the combustion chamber of DI diesel engine was measured and related it to the sound pressure level (SPL) in decibel (dB). It has shown a reduction in noise levels as the engine speed increased. Figures 6 to 8 give the behavior of each fuel alone, while Fig. 9 illustrates the three fuels behaviors at 2500 rpm (High engine speed). In general, engine noise levels increase from low to medium loads then it reduce for high loads. Engine noise level relatively increases from low to medium speeds, and then it reduced for high speeds. Compared to other fuels (in Fig. 9) LPG still resulting in higher noise levels at maximum speed.

Effect of pilot fuel injection timing

Fig. 10 illustrates the effect of injection timing of pilot diesel fuel on the noise levels of the dual fuel engine running on LPG or NG as main fuel at 1500 rpm and middle load.

The effect of injection timing when advancing the pilot fuel injection results in an increase in ignition delay period of the fuel which in turn will lead to the combustion of large diesel fuel mass or bigger flame to propagate at higher speed. This may have caused the combustion to start earlier and the maximum pressure to increase resulting in higher noise levels.

This may be attributed to the increase in ignition delay of the diesel fuel, since the liquid fuel is injected earlier in lower air pressure and temperature. The longer delay period would result in higher pressure rise rate. With the presence in gaseous fuel in the mixture, any advance in pilot injection would result in longer ignition delay period and the pressure rise rate is expected to increase.

Middle injection timing of about 30o to 37.5oBTDC caused lowest SPL as seen in Fig. 10. Retarding injection timing caused high pressure rates resulted in higher SP levels.

The effects of pilot fuel mass percentage

Fig. 11 illustrates the effects of pilot fuel mass on the sound pressure levels. It may be seen that the noise levels increased as the mass of pilot fuel (or md/ (md+mg)) increased. This include a greater energy release on ignition, correspondingly improved pilot injection characteristics, a larger size of pilot mixture enveloped with a greater entrainment of the gaseous fuel, a larger number of ignition centers requiring shorter fame travels, higher rates of heat transfer to the unburned gaseous fuel–air mixture and an increased contribution of hot residual gases.

The combustion noise first increased with increasing the mass of pilot fuel. The employment of a large pilot fuel quantity can lead to successful flame propagation and, consequently, leads to increasing the pressure rise rate which leads also to the knocking early. This indicates that using a greater pilot fuel quantity to enhance the combustion process at low loads, will lead to increasing the tendency to knock at high loads.

However, more increase of pilot fuel mass (higher than md/(md+mg) of 30%) leads to a decrease in the pressure rise rate. Increasing the mass of pilot fuel in the mixture means using less mass of the gaseous fuel which in turn may lead a decrease in the in the ignition delay period of the mixture. Also using more pilot fuel produces bigger and bigger initial flame which propagate easier with less pressure rise rate.

4. Conclusions

This work presents practical measurements of the pressure sound levels variation of a four cylinders DI Fiat engine working on dual fuel mode of diesel and LPG and compared to diesel-NG and pure diesel fuel. From the study carried out the following conclusions may be drawn:

- The observed values of the combustion noise in dual fuel engine are strongly dependent on the type of gaseous fuels used and their concentrations in the cylinder charge.
- Dual fuel engine using LPG as main fuel exhibits higher combustion noise than that using NG.
- Advancing the injection timing of the pilot diesel fuel for dual fuel engine using LPG as main fuel resulted in an increase in the combustion noise. Injection timing of about 30 to 37.5^{o} BTDC resulted in the least combustion noise.
- Increasing the mass of pilot diesel fuel (from 17.5 to 30%) resulted in an increase in the combustion noise, while more

increasing (from 30 to 45%) resulted in reducing combustion noise.

- Increasing the engine speed resulted in a decrease in the combustion noise.

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Notations

BMEP	brake mean effective pressure (kN/m^2)
bp	Brake power (kW)
CR	compression ratio
CA	crank angle
^{o}BTDC	degree before top dead centre
dB	Decibel
DI	direct injection
IT	Injection timing (^{o}BTDC)
LCV	Lower calorific value (kJ/kg)
LPG	Liquefied petroleum gas
N	engine speed (rpm)
NG	Natural gas
T	engine torque (kN.m)
V_{sn}	swept volume (m^3)

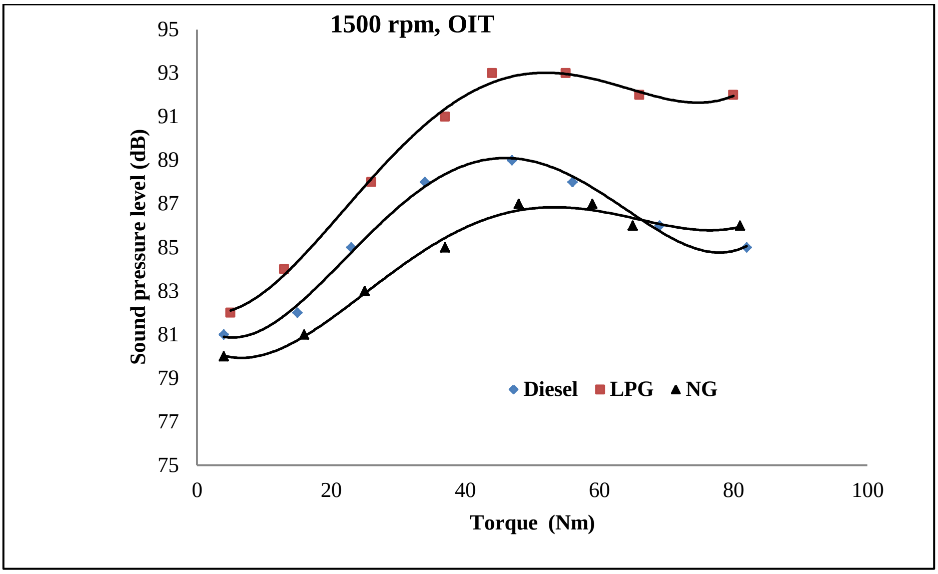

Fig. 5, The Effect of Load on Noise Levels for Variable Fuels at Constant Engine Speed and Optimum Injection Timing.

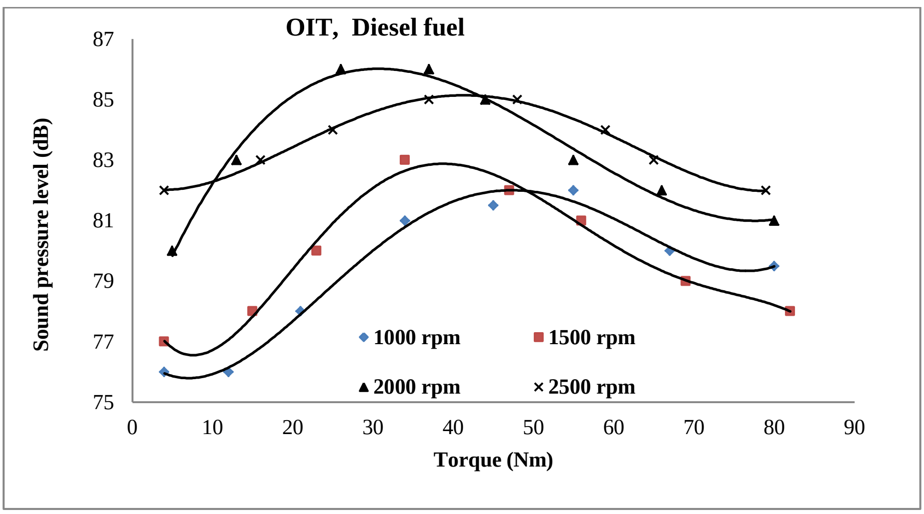

Fig. 6, The Effect of Load on Noise Levels for Diesel Fuel at Variable Engine Speed and Optimum Injection Timing.

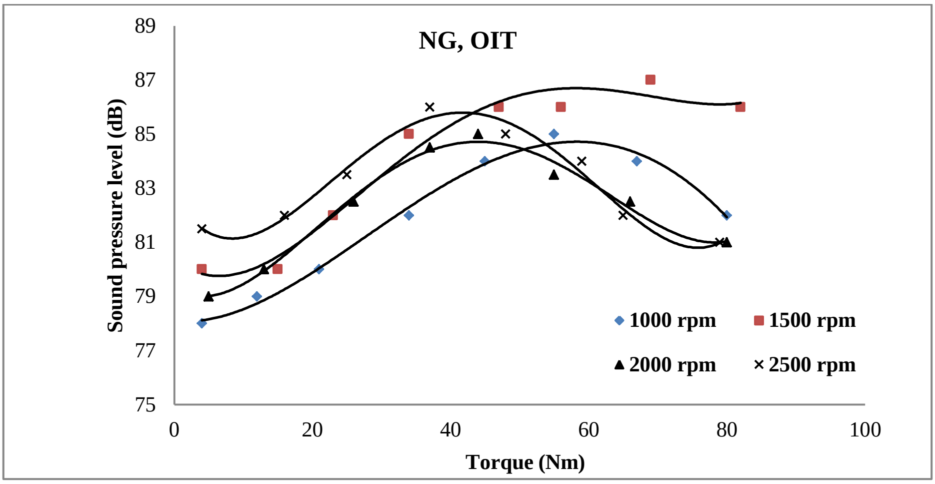

Fig. 7, the Effect of Load on Noise Levels For Duel Fuel (Diesel+NG) At Variable Engine Speed and Optimum Injection Timing

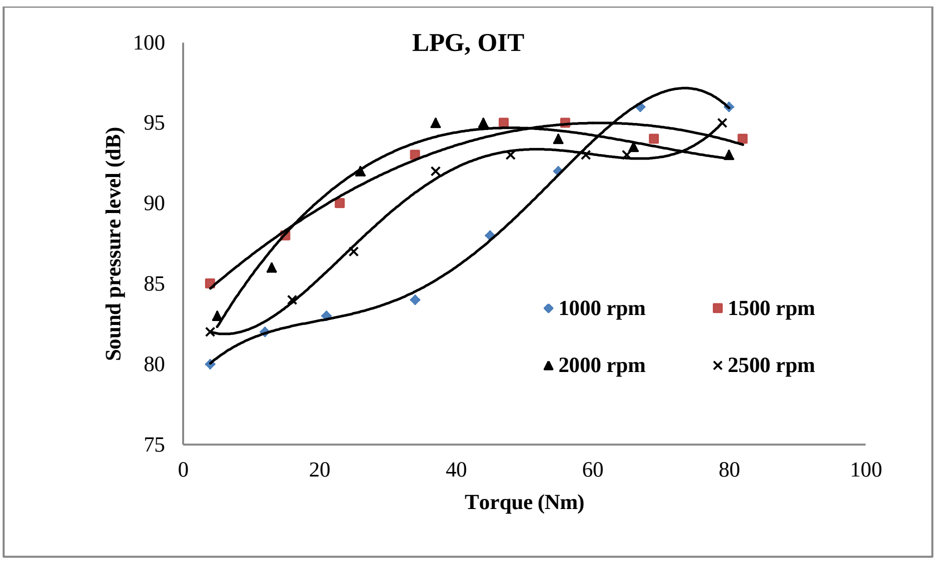

Fig. 8, the Effect of Load on Noise Levels For Duel Fuel (Diesel+LPG) At Variable Engine Speed and Optimum Injection Timing

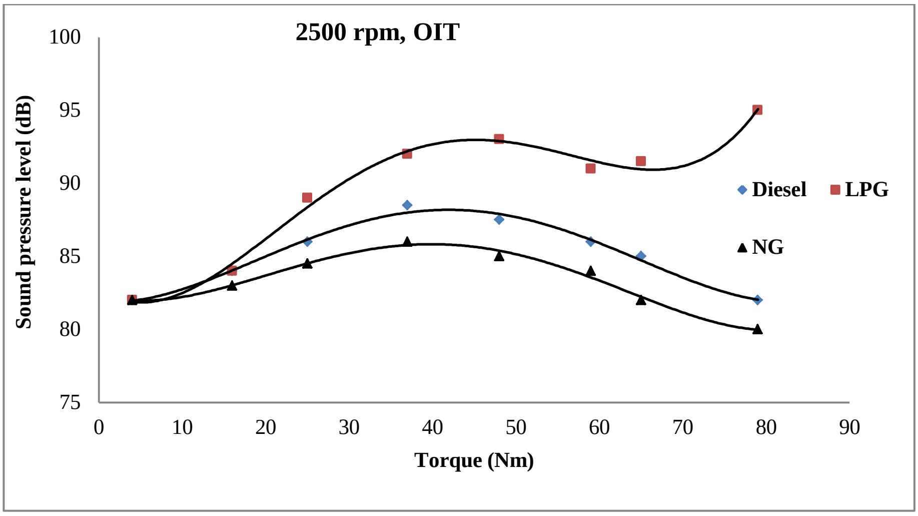

Fig. 9, The Effect Of Load On Noise Levels For Variable Fuels At Constant High Engine Speed And Optimum Injection Timing.

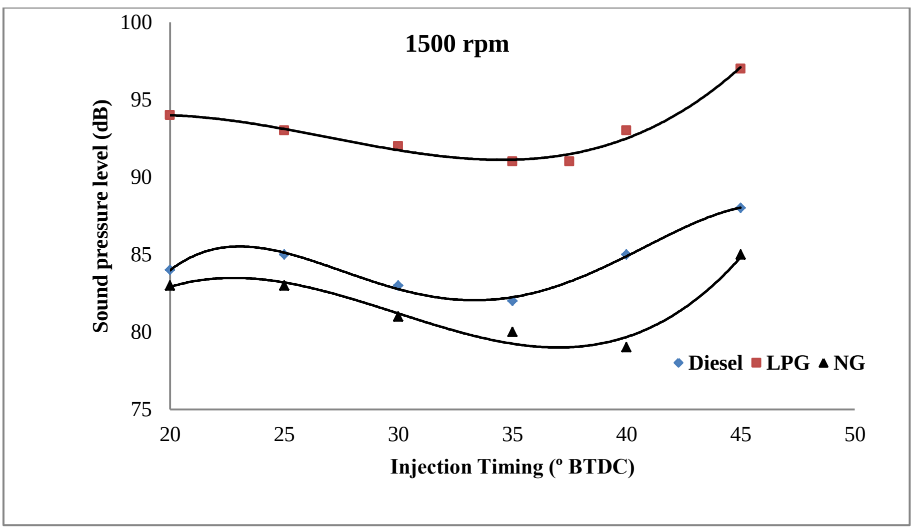

Fig. 10, The Effect Of Pilot Fuel Injection Timing On Noise Levels For Variable Fuels At Constant Engine Speed.

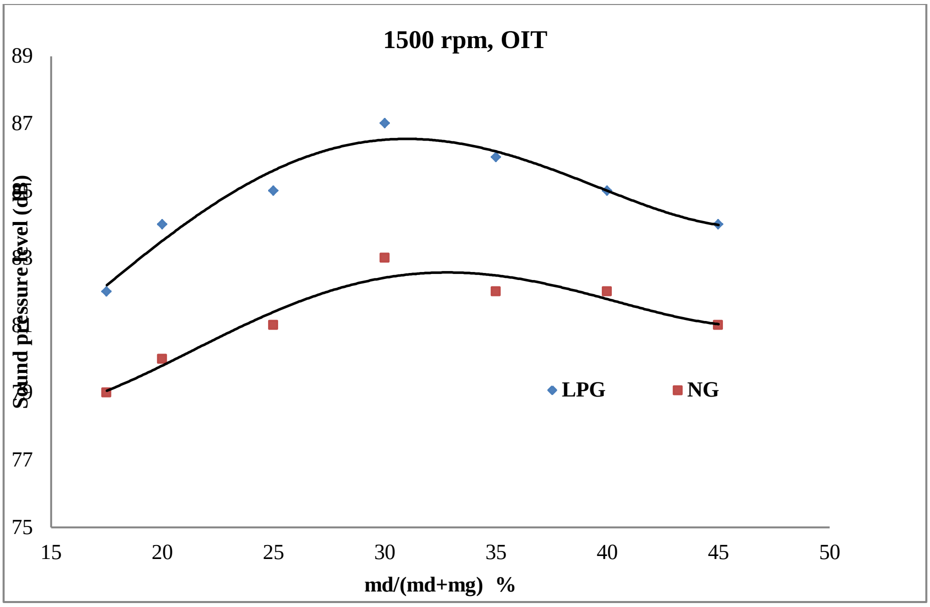

Fig. 11, The Effect Of Pilot Fuel Percentage On Noise Levels For Variable Fuels At Constant Engine Speed.

تأثير بعض العوامل التشغيلية على الضوضاء الناتجة من محرك متعدد الأسطوانات يعمل بنظام وقود ثنائي

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المستخلص

يمكن للضوضاء الناتجة عن الأحتراق أن تؤثر تأثيرا مباشرا على البيئة المحيطة، وفي هذة الدراسة أخذت قياسات للضوضاء الناتجة عن استخدم محرك متعدد الاسطوانات، رباعي الأشواط نوع فيات، حوّر للعمل كمحرك بوقود ثنائي، يعمل بوقود الديزل والغاز النفطي المسال.

ركزت الدراسة على تأثير بعض المتغيرات التشغيلية ، وتتضمن هذة المتغيرات حمل المحرك، توقيت حقن الوقود الدليلي، كتلة الوقود الدليلي وسرعة المحرك. بينت النتائج أن استخدام الغاز النفطي المسال (LPG) كوقود أساسي في خليط الوقود الثنائي يعطي ضوضاء محرك أعلى من حالة استخدام الوقود الطبيعي (NG) أو وقود الديزل بمفرده. كما أظهرت النتائج أن تقديم توقيت حقن الوقود الدليلي عن التوقيت الأمثل يرفع مستويات ضغط الصوت.

الكلمات الرئيسية: محرك وقود ثنائي، الغاز النفطي المسال، الغاز الطبيعي، توقيت الحقن، كتلة الوقود الدليلي، سرعة المحرك.