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Experimental Investigation of the Effects of Some Operating Diesel Engine Variables on Emitted Particulate Matters (PM)

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Abstract

The diesel engine is the most efficient prime mover commonly available today. Diesel engines move a large portion of the world's goods, power much of the world's equipment, and generate electricity more economically than any other device in their size range. But the diesel is one of the largest contributors to environmental pollution problems worldwide, and will remain so, with large increases expected in vehicle population.

This experimental study has been conducted with direct injection diesel engine and particulate matters (PM) concentrations were measured at variable operating variables. The results show that PM concentrations influence by changing equivalence ratio, load, engine speed and injection timing.
Key words: PM, Equivalence Ratio, Speed, Injection Timing, Load

دراسة عملية لتأثير بعض المتغيرات التشغيلية لمحرك ديزل على السناج المنبعث

الخلاصة

يعد محرك الديزل من أعلى المحركات الأولية المتوفرة اليوم كفاءة، إذ تعمل محركات الديزل في نقل جزء كبير من بضائع العالم، وتجهز قدرة لمعظم الأجهزة، كما تولد طاقة كهربائية أقتصادية أكثر من أي جهاز آخر في مدى حجومها. ولكن محركات الديزل هي أحد أعظم المساهمين في مشاكل التلوث البيئي حول العالم، وستبقى كذلك، مع الزيادة الواسعة في أعداد السيارات المتوقعة.تمت هذة الدراسة العملية بمحرك ديزل ذي حقن مباشر وتم قياس تراكيز المواد الدقائقية (السخام) في ظروف تشغيلية مختلفة. بينت النتائج أن تراكيز المواد الدقائقية تتأثر بالتغير في النسبة المكافئة والحمل و سرعة المحرك وتوقيت الحقن.
الكلمات الدالة: المواد الدقائقية، النسب المكافئة، توقيت الحقن، الحمل

Nomenclatures

PM	particulate matters
CO	carbon monoxide
HC	unburnt hydrocarbons
bp	brake power
bmep	brake mean effective pressure
CN	Cetane Number
V_t	drawn air total volume (m^3)
Q_t	elementary and final air flow rate through the device (m^3/sec).
t	sampling time in (min).
w_1	filter weight before sampling operation in (g).
w_2	filter weight after sampling operation

Introduction

Like any other internal-combustion engine, diesel engines convert the chemical energy contained in diesel fuel into mechanical power. Diesel fuel is injected under pressure into the engine cylinder, where it mixes with air and combustion occurs. The lean nature of the diesel-air mixture results in a cooler combustion environment with smaller volumes of carbon monoxide (CO) and hydrocarbons (HC). However, diesel engines emit a complex mixture of air pollutants, composed of gaseous and solid material. The visible emissions in diesel exhaust are known as particulate matter (PM), which includes carbon particles or "soot" [1 &2]. Diesel exhaust also contains a variety of harmful gases and over 40 other known cancer-causing substances [3].

While the operational advantages of diesel engines are clear, diesel fuel is a major contributor to particulate matter (PM). Diesel particulate emissions are of increasing concern as they are small, often less than 10 microns in size, and consist of a complex mix of engines oils, sulfates and inorganic materials. These particles have been identified by health experts as contributing to a variety of lung related illnesses including asthma, emphysema and bronchitis. US Protection Agency identified diesel PM as a “likely human carcinogen,” and followed this with new stringent standards aimed at reducing emissions from on-road vehicles by as much as 90 percent [4 & 5].

Smoke may be defined as particles, either solid or liquid (aerosols), suspended in the exhaust gases, which obstruct, reflect, or refract light [6]. Diesel engine exhaust smoke can be categorized under two headings:

1. Blue/white in appearance under direct illumination, and consisting of a mixture of fuel and lubricating oil particles in an unburnt, partly burnt, or cracked state [7].

2. Grey/black in appearance, and consisting of solid particles of carbon from otherwise complete combustion of fuel. The blue component derives mainly from an excess of lubricating oil in the combustion chamber, resulting from deterioration of piston ring sealing, or value guide wear, and is thus an indication of a need for mechanical overhaul. However unburnt fuel can also appear as blue smoke. The white component, on the other hand, is mainly a result of too low a temperature in the combustion chamber during the fuel injection period [8].

Fuel properties are also capable of influencing smoke emissions. Thus, increasing the cetane number will reduce the tendency to produce white smoke, as also will increased volatility, usually indicated by reduction in mid-boiling point. On the other hand, chemical composition, cetane number and volatility all affect black smoke in a complex way, while increasing relative density will increase black smoke, for the same fuel pump setting, merely as a result of the increased mass of fuel injected [9].

PMs are contributed to low load operation and large load swings causing unburnt fuel in the exhaust. Particle emissions are also influenced by the fuel ash and sulphur content as well as poor combustion due to insufficient engine preheating. Particle emissions from a diesel engine are typically low during steady state operation at higher loads, but during startup, low load operation, and large load swings, it is common to see a puff of black smoke from the exhaust stack. Smoke emissions draw attention in pristine areas, also some local regulations are now prohibiting smoke emissions during operation in coastal areas [10].

The principle exhaust treatment technologies that have been successfully used to reduce diesel PM from diesel-fueled engines used in land-based applications are diesel particulate filters (DPF), Diesel oxidation catalysts (DOC), flow through filters (FTF) or combinations of technologies [11].

The aim of this paper is to study practicaly the PM emitted from unmodified four cylinders direct injection diesel engine fueled with conventional diesel fuel.

Experimental Setup

Experimental apparatus of engine under study is direct injection, water cooled four cylinders, in-line, naturally aspirated FIAT diesel engine (Fig. 1) 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 following equations were used in calculating engine performance parameters:

Brake power

$$bp = \frac{2\pi * N * T}{60 * 1000} \quad kW \qquad \text{.... (1)}$$

Brake mean effective pressure

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

Conventional diesel fuel (CN=46.8) was operated on the engine; meanwhile combustion characteristics were measured and analyzed at the same brake mean effective pressure (bmep) and speed, to clarify the effect of engine variables on emitted PM emissions.

Low volume air sampler type Sniffer L-30 (Fig. 2) was used to collect emitted PMs. Whatmann-glass microfilters were used to collect PMs. These filters were weighted before and after the end of sampling operation which extend for one hour. PMs concentrations were determined by the equation:

$$PM \ in \left(\mu g/m^3\right) = \frac{w_2 - w_1}{Vt} \times 10^6 \qquad \text{.. (3)}$$

Where: PM = particulate matters concentration in (µg/m^3).
w_1 = filter weight before sampling operation in (g).
w_2 = filter weight after sampling operation in (g).
Vt = drawn air total volume (m^3)

Vt can be found by the equation:

$$Vt = Q_t \cdot t \qquad \text{...(4)}$$

Where:
Q_t= elemintary and final air flow rate through the device (m^3/sec).
t = sampling time in (min).

Each filter was put in plastic bag temporarily at the end of collecting samples operation until analyzing and studying the results using light microscope.

Results and Discussion

Fig. 4 shows the effect of equivalence ratio on emitted PM at constant speed 1500 rpm and medium load (44 kN/m^2). Emitted PM was high at very low equivalence ratio (Ø≤0.3). The range on the minimum PM concentration was ranged between (0.3≤Ø≤0.6) that produced the higher brake power. At equivalence ratios (Ø≥0.6) PM concentrations start to increase highly, due to incomplete combustion caused by improper mixing accompanied with increasing fuel quantity.

Load effect on PM concentration at constant speed was studied as Fig. 5 represents. PM concentrations reduced from low to medium loads. For loads in the range of 20-60 kN/m^2 the concentrations tend to be stable. At loads higher than 60 kN/m^2 PM concentrations increased significantly. At low loads the combustion chamber temperature is low, which lead to bad combustion especially for higher hydrocarbon molecules resulting in higher PM concentration. At medium loads the chamber temperature suitable and adequate combustion led to this approximate stability. At high loads, more fuel was injected to maintain engine speed, accompanied with higher combustion chamber temperatures causing higher PM concentrations.

PM concentration increased at low and high speeds, and reached it minimum values at medium speeds, as Fig. 6 represents. The high concentrate of PM is due to reduction in volumetric efficiency at low speeds. At high speeds the air-fuel preparation time reduced highly, giving higher PM concentrations.

Injection timing effect on emitted PM was studied as Fig. 7 shows. Retarding injection timing reduced the available time for air – fuel mixture preperation producing high PM concentration. Advancing injection timing increased preparation time and contain fuel delay period producing better combustion with less PM concentration. This is right for working without knock. Advancing injection timing was limited by engine appearance. In this work the knock phenomenon effects on PM concentration were not investigated.

Conclusions

1- PM concentrations emitted from diesel engine depend on many design and operating variables.
2- Working at equivalence ratios that give the maximum brake power values produce lower PM concentrations.
3- Working at low or high equivalence ratios produce higher PM concentrations.
4- Engine operation at medium loads gives the minimum PM concentrations vales.
5- Engine operation at low or high loads gives higher PM concentrations.
6- Low and high speeds produce high PM concentrations, while medium speeds produce lower concentrations.
7- Retarding injection timing causes high PM concentration; on the contrary, advancing injection timing results in lower concentrations.

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Fig. 1, photographic picture of the experimental rig. Fig. 2, drawing air equipment to collect PM type Sniffer

Fig. 3, light microscope used to study on PM specifications

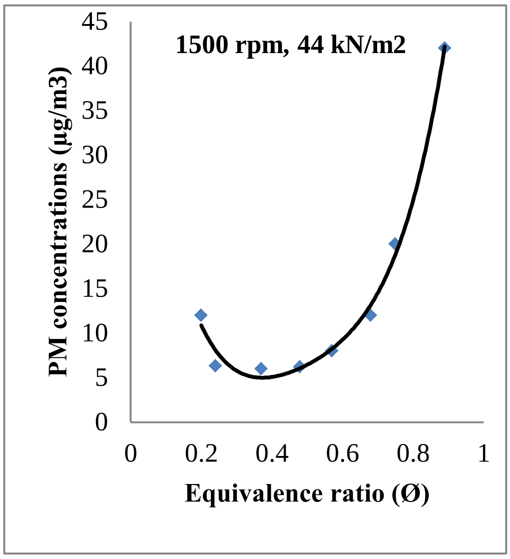

Fig. 4, Wide range of equivalence ratios effect PM concentration at 1500 rpm and medium load.

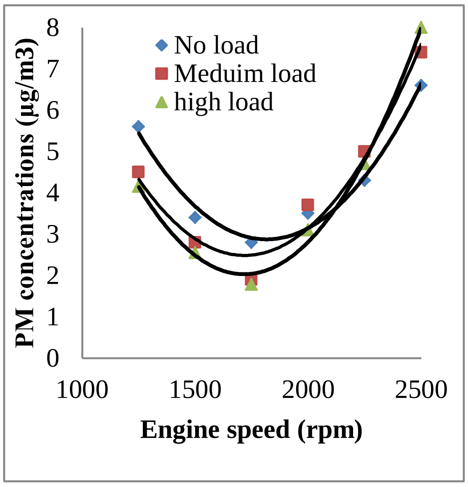

Fig. 5, Load effect on PM concentrations at 1500 rpm and Ø=0.55

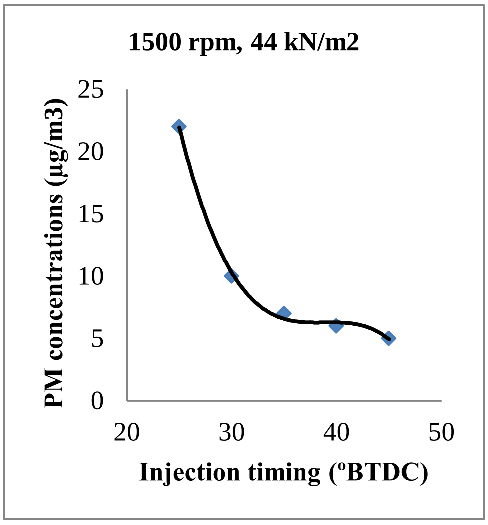

Fig. 6, Engine speed effect on PM concentrations at variable loads.

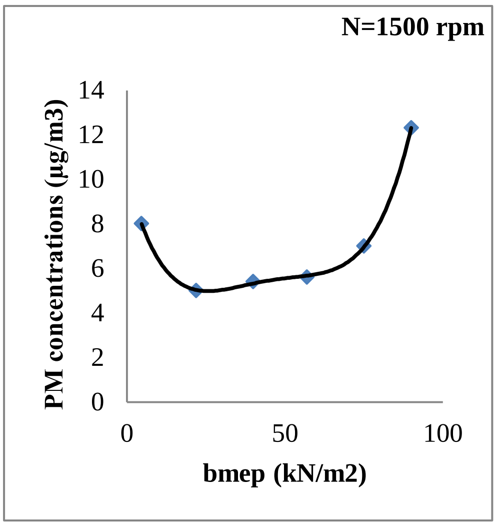

Fig. 7, Injection timing effect on PM concentration at constant engine speed (1500 rpm) and medium load.