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The effect of diesel engine cold start period on the emitted emissions

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Abstract—Diesel engines emit pollutants from their exhaust that cause environmental pollution reached minutes stages. The attention has increased by reducing the burning of fossil fuels, especially diesel pollution rates, worldwide. The engine startup process can be considered as a complicated operation of the engine that causes high pollution rates. In this research study, the pollutants emitted from direct injection, four cylinders diesel engine during the startup period was measured and analyzed in the conditions of low temperatures of the winter in Baghdad, Iraq. The effect of engine starting speed was examined to evaluate the impact of engine starting speed on the emitted emissions. The results showed high levels of carbon monoxide and unburned hydrocarbons and lower carbon dioxide. Also, the nitrogen oxides in the exhaust gasses have emerged despite the cold operation. The smoke opacity rose at starting speed of 800 rpm, as well as, the engine noise increased at this speed compared to the rest velocities.

Keywords- Startup period, diesel engine, emissions, engine starting speed.

1 Introduction

The concern of the growing emissions levels from internal combustion engines and their environmental impacts become a reality. There are many efforts to eliminate and reduce it as possible as it can. The emitted emissions from ICE at cold starting have a growing interest because it contributes in the total vehicles emissions especially that operate on diesel fuel by a large portion. For example, it was found that the diesel engine may emit up to seven times more particulates through a cold starting period compared to the start operating under the warm weathers [1], [2].

In many applications and areas, diesel engines should be operated at low ambient temperatures. In these circumstances, the engine cold starting process is divided into two phases. The first step starts from the beginning from rotating the flywheel for the first time while the second phase includes the period from the first launch to reaching a stable idle operation. During this time, the combustion shows a lack of stability reflected in misfires. This period lasts until the engine reaches a consistent idling speed [3]. The defects of misfire combustion at cold starting clarified by the large white smoke emission and potentially high operating costs. The successful cold starting process depends on the accurate balance between heat transfer and the self-ignition reactions at least until a maximum speed are achieved [4].

The working conditions at low temperatures reduce battery power and cause increased both friction and the lubricating oil viscosity of the engine. Conventional diesel engines are usually equipped with glow plugs help in the starting. The little battery charge causes these glow plugs to lose its effectiveness. These heating resistance elements are placed close to the injector, and causing adequate heating to the fuel in a local area, which speeds up the evaporation of fuel and its self-ignition [5].

Cold starting leads to a higher demand for higher crankshaft rotation and lower speed for starting. However, under extreme heat, and conditions of great engine starter power, they are not enough to increase the engine speed above the low idle speed [6]. As a result, a longer start time will occur. The compression temperature, which depends on external factors (ambient temperatures), engine design factor (compression ratio), and operational effects (load and speed), affects both the physical and chemical delay period. At cold starting, accelerating the high crankshaft movement is preferred to reduce heating time and blow-by losses. The high temperature and pressure of the combustion chamber are desirable to limit the ignition delay period. On the other hand, the use of high crankshaft moving speed causes a reduction in the required time for the self-ignition reactions, and thus may hinder the starting process [7].

Currently, the unburned hydrocarbons, carbon monoxide (CO), and nitrogen oxides (NOx) are removed from the engine exhaust through using catalysts during the engine operation. The catalyst utilization results in lower levels of exhaust pollutants emitted and in much cleaner cars exhaust. However, the catalysts employed in conventional cars are not active at temperatures lower than 400°C, which results in significant amounts of pollution during the cold start phase. In general, in the first 120 seconds of operation, the most significant levels of pollutants are achieved, especially the emission of HC. This is because the cold start process occurs when the combustion chamber walls are cold, and with limited fuel vaporization, which led to massive levels of heat transfer and a richer air-fuel mixtures into the combustion chamber resulting in high misfire levels that result in producing high unburned gasses [8], [9].

Many researchers have shown that ambient temperatures significantly affect the pollutants emitted from engines exhaust. The emissions concentrations are increased at the cold starting operation, especially in cold days [10], [11], [12], [13]. Bielaczyc et al. studied the exhaust emissions from the direct injection (DI) diesel engine during the cold and hot start. The study results showed that carbon monoxide (CO) and hydrocarbons (HC) emitted during the first 60 seconds had higher limits of 40 per cent of the total emissions from a cold start in the first three minutes, and the particles (PM) will be more than 50 per cent. The study also showed that the amount of HC and PM concentrations emitted during the first 3 minutes of the cold start were several times higher than the initially hot state while the difference in the value of the carbon monoxide are almost two orders of magnitude. Cold starting caused exces-

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sive exhaust emissions of all the emitted pollutants from diesel engines [14], [15].

This work is a part of continuous efforts in the Energy and Renewable Energy Technology Center to enhance the Iraqi traditional fuels and to introduce relative renewables [19-35]. The aim of this paper was to evaluate practically the emitted emissions from a diesel engine in cold winter days in Baghdad-Iraq.

2 Experimental Setup

2.1 Equipment

In this study, the experimental engine used was a direct injection, natural aspirated, four cylinders, water cooled diesel engine type Fiat. Table 1 illustrates the main engine specifications. A hydraulic dynamometer is attached to the engine used to control the torque subjected to it. The carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxide (NOx), and unburned hydrocarbon concentrations were measured by an emissions analyzer type Multi-gas mode 4880. The smoke opacity of the exhaust gas was measured continuously with a partial flow opacity-meter type AVL 439. This device is particularly suitable for dynamic testing measurements and has a response time less than 0.1 s with an accuracy of 0.1%.

TABLE 1
Tests Engine Specifications

Engine type	4cyl., 4-stroke
Engine model	TD 313 Diesel engine rig
Combustion type	DI, water cooled, naturally 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
	Hole nozzle
Fuel injection nozzle	10 nozzle holes
	Nozzle hole dia. (0.48mm)
	Spray angle= 160o
	Nozzle opening pressure=40 Mpa

2.2 Material

In this study, Iraqi conventional diesel fuel was used as it is the traditional working fuel in the area of Iraq. This diesel type characterized by its high sulfur levels (8765 ppm) and moderate cetane number (CN=49) [16]. The fuel supplied from Al-Doura Refinery in Baghdad. Table 2 illustrates the used diesel fuel specification as provided by the supplier.

2.3 Tests Procedure

The tests began when the used engine was left to start by running the starter without any load until the stable idle speed was achieved. The engine starting speed was varied to 800, 900, and 1000 rpm. Exhaust emissions CO_2, CO, HC, NOx, noise and smoke opacity were measured in intervals during the startup period. The time of engine startup was varied depending on the engine coolant and lubricant temperature. As Iraq is a warm country in general, the tests were conducted in the winter season, and every test was accomplished in the first morning. The tests were performed on the days when engine coolant water and lubricant oil temperatures were at 5°C. Each speed test was repeated three times to confirm its repeatability and to reduce the measurement uncertainty resulted from human error.

TABLE 4
Diesel fuel used in the recent study properties

Specification		Diesel
Chemical formula		C10.8H18.7
Mole weight	(g)	148.3
Density	(g/cm³ at 20ºC)	0.84
Boiling point	(ºC)	180-330
Heat of evaporation	(kJ/kg)	280
Lower heat value	(MJ/kg)	42.5
Liquid viscosity	(cP at 20ºC)	3.03
Surface tension	(mN/m at 20ºC)	34.1
Flash point	(ºC)	78
Stoichiometric air fuel ratio		14.6
Cetane number		49
Auto-ignition	(ºC)	235
Carbon content	(wt%)	87.4
Oxygen content	(wt%)	0

3 Results and Discussion

The engine emitted emission during the combustion instability of the cold starting period of 4 cylinders; direct injection diesel engine was investigated. The experiments conducted at low ambient air temperatures. The cold start phase of the engine based on its characteristics such as the engine displacement, the compression ratio, the size of the battery and it's charging status, and the auxiliary equipment. Also, the cold start period depends on the injection system and cold start aid. The characteristics of the engine and fuel oil, air transport system all have an impact on the cold start and warm-up phase. The study results revealed the following:

3.1 3.1 Carbon Monoxide and Dioxide

Carbon monoxide (CO) is a tasteless, odorless, and colorless gas. The CO-existence in the exhaust gas reveals that there is an incomplete combustion of fuel. The temporary accumulation of high levels of this gas is possible to reach harmful levels in parking lots and large carriers, traffic jams, or busy streets, especially during cold weather when the fuel combustion misfire reaches its peak. Carbon monoxide is chemically stable at low temperatures, and the high concentrations of it may be a hazard to environment and humans and animals health.

Fig.1 presents the CO concentrations variation with time during the startup period. CO concentrations were at its high levels of the starting period began and reduced with time. The engine startup at 800 rpm took more time and emitted higher CO levels. The engine run at 900 or 1000 rpm emitted relatively equal CO concentrations through the starting period. The CO concentrations levels resulted from the misfiring occurred during the studied period which grows due lower air temperatures. CO levels are reduced with increasing starting up velocity by 0.97 and 20.4 for 900 and 1000 rpm respectively compared to the emitted concentrations at 800 rpm.

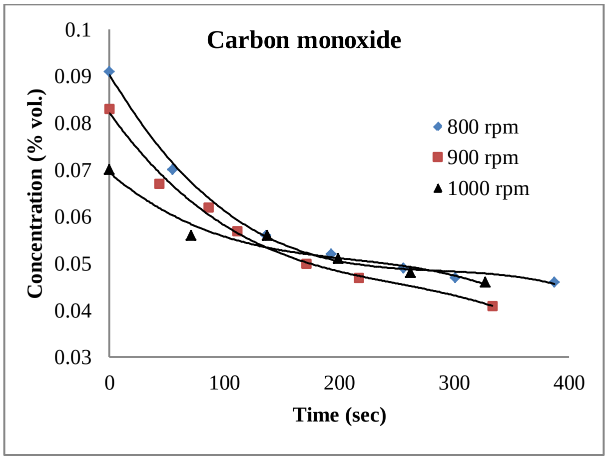

Fig. 1. Carbon monoxide variation with time during the starting period.

Fig. 2 shows the CO_2 concentrations variation with time during the startup period. The CO_2 concentrations show similar trends with relatively higher levels of engine speed 900 rpm while lower concentrations levels occurred at 1000 rpm. The combustion misfiring happens when there is a rich mixture of some areas of the combustion chamber that produces carbon dioxide in addition to the rest of the pollutants. Therefore, emitted CO_2 concentrations are little and volatile by the frequency of combustion misfire occurrence. CO_2 levels reduced by 0.176 and 1.936% for 900 and 1000 rpm respectively compared to 800 rpm.

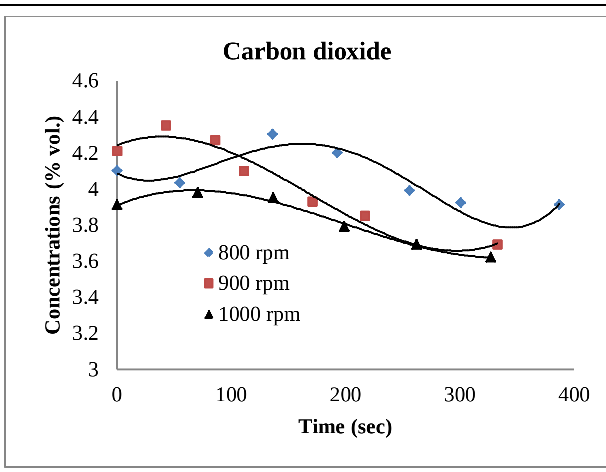

Fig. 2. Carbon dioxide variation with time during the starting period.

3.2 Unburned hydrocarbons

Carbon dioxide and water emissions will be inevitable as by complete combustion of hydrocarbon fuel. Sometimes, several hydrocarbon compounds result from the combustion such as ethene, toluene, and formaldehyde. These compounds are emitted due to incomplete oxidation reactions which were stopped before its end. The increase in the concentration of HC in the exhaust produces from enriching of the air-fuel mixture higher than the stoichiometric one. The seriousness of unburned hydrocarbons lies in the interaction with the nitrogen oxides resulting from combustion, also, in the outer atmospheric in the presence of sunlight to form ozone layer, producing photochemical smog.

Fig. 3 declares that HC concentrations stated at high rates and increased for the first 100 seconds then they stay constant at 800 and 1000 rpm speeds while they declined for 900 rpm speed. During the first 100 seconds, the emitted HC levels were high which is compatible with most studies. The figure results show that there is a suitable engine speed (900 rpm in our case study) that emits lower HC levels. HC concentrations were reduced by 0.95 and 15.15% for 900 and 1000 rpm respectively compared to 800 rpm.

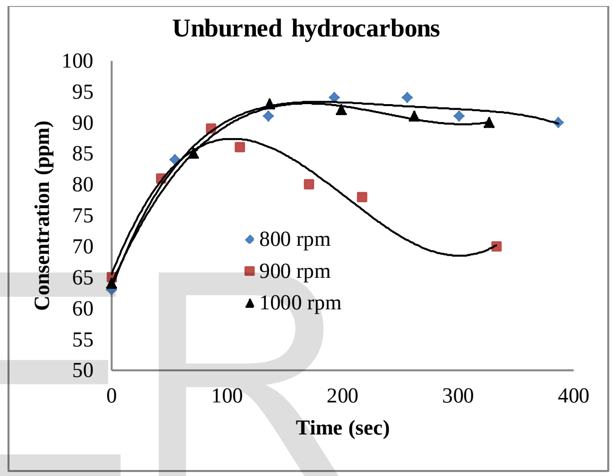

Fig. 3. HC variation with time during the starting period.

3.3 Oxides of Nitrogen

The nitrogen oxides result during the combustion from the nitrogen oxidation in air at high temperature and under certain circumstances. The most important components of NOx are the Nitric oxide (NO), and nitrogen dioxide (NO_2). Some members of this group of these pollutants, especially NO_2, are known to be highly toxic to humans and various animals.

Fig. 4 illustrates the NOx resulted during the startup period. Increasing engine speed increases the emitted NOx during this time due to higher generated temperature inside the combustion chamber. At low engine speed as 800 rpm, the emitted NOx concentrations were significant due to the engine used has no control on exhaust emission. Also, if the engine is equipped with catalyst it will not function as its temperature is lower than 400°C as Ref. [8] revealed. NOx concentrations increased by 11.07 and 5.166% for 900 and 1000 rpm respectively compared to 800 rpm levels.

3.4 Smoke opacity

Smoke Opacity is a measurement of the optical characteristics of the diesel exhaust. It measures visible black smoke emissions using physical phenomena such as the extinction of a beam of light through scattering and absorption [17]. In general, the use of scale blackout is one of the simplest methods of measuring PM and least expensive compared to most other tools used for this purpose. This measure concerns with large diameters particulates of less than 200 nm, and indifference to small diameters particulates of less than 50 nm. The opacity readings depend on the particle sizes, and the reading becomes low when the measured particulates sizes are small [18].

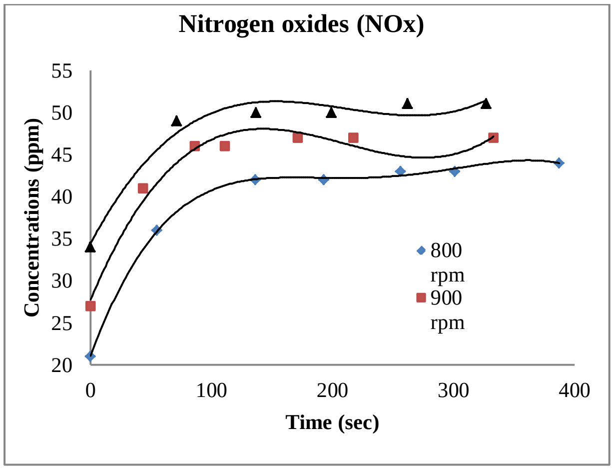

Fig. 4. NOx variation with time during the starting period.

Fig. 5 manifests the impact of engine starting speed on the exhaust opacity during startup. High levels of opacity were resulted at 1000 rpm compared with other speeds. Increasing engine startup speed means increasing the injected fuel in the cold combustion chamber which causes this phenomenon. Starting the engine with low speed reduces the injected fuel and results in low opacity levels. However, the indicated emitted opacity is high levels that impact the environment and human health. Also, these levels are too high compared with resulted opacity from engine operates at stable conditions. Smoke opacity reduced by 10.93% for 900 rpm and increased by 7.8% at 1000 rpm compared to 800 rpm opacities.

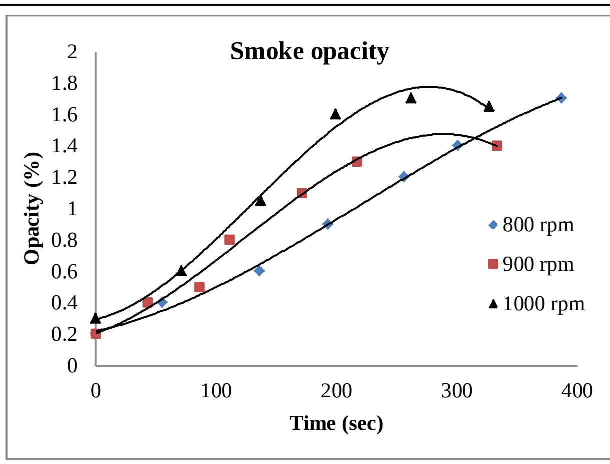

Fig. 5. Smoke opacity variation with time during the starting period.

3.5 Noise Pollution

Noise effect depends on various factors, including, vehicle condition and driver behavior. In the case of the start-up, it is usually conducted in the home or public garage. The noise can affect human health in many ways as the World Health Organization (WHO) indicated, including the reaction of annoyance, sleep disturbance, interference with communication. Noise effects can be reflected on the driver performance, social behavior, hearing loss, and distraction.

Fig. 6 represents the sound pressure levels during the startup period. The beginning of the startup period causes high noise which reduces with time to reach its lowest level since the start of the warm up or idle period. The engine operation at the low engine speed as 800 rpm cause the highest noise compared with the other tested speeds. This noise increment resulted from high engine vibration during the startup period. Engine noise reduced by 2.68 and 17.98% for 900 and 1000 rpm respectively compared to 800 rpm.

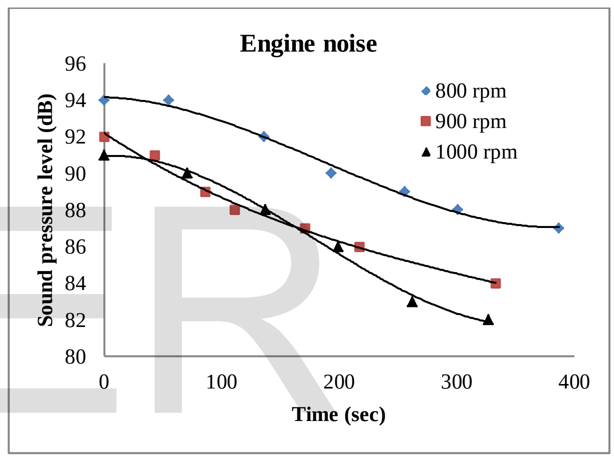

Fig. 6. Engine noise variation with time during the starting period.

Conclusions

A four cylinder, direct injection diesel engine type Fiat was used in this study to evaluate the emitted emissions from the engine during startup period at cold winter days in Baghdad-Iraq.The CO and HC emissions increased profoundly at this time at the expenses of the CO_2 concentrations which remain small. In spite of the cold outdoor air temperature and the cold combustion chamber, significant levels of NOx were measured during this period. The local enrichment in some parts of the combustion chamber caused these concentrations. The smoke opacity levels are high during this period, and it was increased highly at the beginning of the starting up process. The engine noise levels were high through the period and were higher at the start of the process.

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