STUDY UPON THE EMISSIONS DURING COLD START OF A DIESEL ENGINE

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***Abstract**:*

Diesel engine development for use in light-, medium- and heavy-duty road vehicles is mainly driven by more and more stringent emission standards. Apart from air quality related emissions, such as nitrogen oxides and particulates, also greenhouse gas (GHG) emissions are a big concern nowadays.

This paper is about a bibliographic study upon the control of exhaust emissions from diesel engines during the start-up process, which has become more important and received more attention throughout the world in recent years because of the gradually stringent legislated levels for CO, HC, NOx and particulate matter emissions of diesel engines.

This study precedes the actions to be followed within the frame of a research project granted by the Romanian Council for Scientific Research in the Higher Education (CNCSIS)

Keywords: diesel engines, startability, low temperatures, cold-start, exhaust emissions

INTRODUCTION

The startability of diesel engines degrades as the ambient temperature falls, in particular, to the borderline or lower temperature. The essential cause is the deterioration of in-cylinder combustion resulting from worsening of combustion conditions. Combustion instability and emissions are serious problems during cold start of internal combustion engines. Many investigations have been conducted on cold start of internal combustion engines, and they concentrated on startibility and emissions [1, 2, 3, 4]. Further on, several explanations are provided according to the specific literature. For diesel engines, the ignition of diesel fuel is dependent on the compression temperature, compression pressure, fuel properties, and fuel injection characteristics. Blow-by and heat transfer during cold start are aggravated owing to the low cranking speed and low initial temperature of the combustion chamber wall. Therefore, the compression temperature and pressure during cold start are much lower than that under normal operating conditions. Thus, the combustion of a diesel engine during cold start is unstable, and even misfiring, which resulted in poor startability and serious emissions. Bielaczycet al. [2, 3] investigated exhaust emissions from a direct-injection (DI) diesel engine during cold and hot start. Their results showed that carbon monoxide (CO) and hydrocarbon (HC) emissions during the first 60 s are more than 40 per cent of the total emission for 3 min cold start, and particulate matter (PM) even more than 50 per cent. They also reported that the amounts of HC and PM emissions during the first 3 min of cold start were several times higher than that of hot start, while the difference in the amounts of CO was almost two orders of magnitude. The phase of cold start makes a considerable contribution to the entire exhaust emissions of diesel engines. In the last decade, the legislated maximum levels for the emissions of diesel engines have been tightened, and further reductions in emissions are desired for the future. This trend suggests that there is urgent need to improve the combustion of diesel engines during cold start.

AMBIENT TEMPERATURE

The effect of the ambient temperature is one of the most critical factors. Obviously, a low ambient temperature results in a low compression temperature and pressure, which would cause poor evaporation of diesel fuel and consequently a long ignition delay. Thus, an increase in the combustion instability and emissions would occur during cold start of a diesel engine, [5].

INJECTION TIMING

Injection timing is also an important factor affecting cold start of a diesel engine. During cold start, the ignition delay is longer owing to the lower peak compression temperature and pressure, but the required crank angle (CA) for the ignition delay becomes much less for a low cranking speed. Therefore retarded injection timing would improve cold startability. However, when the injection timing was retarded excessively, the ignition delay extended late into the expansion stroke. In this case, ignition would start in the expansion stroke far from the top dead centre. In a severe case, this may result in unstable combustion and even complete misfiring, [5].

CRANKING SPEED

The cranking speed also has significant effects on cold startability. While at low cranking speeds there is much time for blow-by and heat transfer in the engine, a higher cranking speed can result in a slight improvement in the peak compression pressure and temperature. However, in this case, the ignition delay may extend late into the expansion stroke owing to the increase in the cranking speed. Therefore, there is an optimum cranking speed for a certain diesel engine during cold start. With regard to the fuel property, the cetane number and volatility have obvious effects on cold start [6]. Good volatility is of benefit to the formation of the air–vapour mixture and improves its combustibility. The cetane number of diesel fuel affects the ignition delay obviously. Although variations in the cetane number from 50 to 60 have a minor effect on the ignition delay, a drop in the cetane number from 50 leads to a significant increase in the ignition delay [7].

EXHAUST VALVE CLOSING (EVC) TIMING CONDITIONS

The in-cylinder residual gas has significant effect on combustion when engines are running. Its magnitude affects the volumetric efficiency and engine performance directly, and the efficiency and emissions through its effect on the working-fluid thermodynamic properties [7]. In recent years, many studies have been conducted on controlling the combustion process of engines using residual gas. In many investigations on homogeneous charge compression ignition (HCCI) combustion in diesel engines, the residual gas fraction is one of the most effective measures for controlling the fuel evaporation and ignition. Shi et al. [8,9] investigated diesel HCCI combustion by injecting diesel fuel into the cylinder during the negative valve overlap period. Their investigations suggested that the thermal effect of residual gas in the cylinder promotes vaporization of the fuel injected before the top centre of the exhaust stroke and reduces the smoke emission significantly. Besides thermal effects, the residual gas fraction also has chemical kinetic and dilution effects, which affected the combustion process significantly. The investigations by Liu and Karim [10] suggested that residual gas has both positive and negative effects on ignition depending on its compositions. Residual gas produced by a partial oxidation reaction has mainly chemical kinetic effects, which promote ignition, while the products of more complete combustion also have significant thermal diluting effects. Kwon et al. [11] investigated the effects of residual gas on the ignition delay through experiments conducted in a constant-volume combustion bomb. They found that the addition of ethane (C2H6) and propane (C3H8) shortened the ignition delay, while the addition of CO and carbon dioxide (CO2) has the reverse effect. During normal operations of a diesel engine, residual gas is the product of complete combustion. However, in the case of a cold start of a diesel engine, residual gas consists of a large quantity of unburned hydrocarbon, fuel vapor, and the products of a partial oxidation reaction. If the residual gas fraction increases during cold start of the diesel engine, its effects on combustion and emissions may be different from those under normal operating conditions. The residual gas fraction is primarily a function of the inlet and exhaust system dynamics, compression ratio, and engine operating conditions [7]. Valve overlap is one of the most important variables that affected residual gas fraction in cylinder. Therefore, the residual gas fraction could be controlled by adjusting the exhaust valve closing (EVC) timing. Experimental studies are made to investigate the effects of the EVC timing on the combustion and emissions of the diesel engine during cold start. [5]

Thus, residual gas fraction has significant effects on combustion in a diesel engine. However, few researchers have studied the effects of the residual gas on startability and emissions of a diesel engine during cold start, in which the components of the residual gas fraction were very different from those under normal operating conditions. [5]

In experiments presented in paper [5], the variable-valve-timing technique was adopted to adjust the EVC timing. The EVC timing and valve overlap duration for every test case is listed in Table 1.

Table 1 EVC timing and valve overlap duration [5]

Case	EVC (CAD) ATDC	Valve overlap (CAD)
1	7	14
2	0	7
3	-7	0
4	-14	-7
5	-21	-14

Opacity during cold start, especially during the initial phase, could be reduced significantly by appropriately advancing the EVC timing. In experiments, the peak opacity of the initial phase in case 4 (EVC was -14 CAD ATDC) achieved the lowest level, which was about 50 per cent lower than in case 1 (EVC was -7 CAD ATDC). For the average opacity of the whole cold-start process, still in case 4, the lowest level was achieved, and it was about 40 per cent lower than in case 1. The residual gas fraction affected the NOx emission during cold start strongly owing to its thermal effect. In experiments, NOx emissions during cold start tended to increase as the EVC timing advanced. The average NOx emission in case 5 (EVC was -21 CAD ATDC) achieved the highest level, which was about twice that in case 1 (EVC was 7 CAD ATDC).

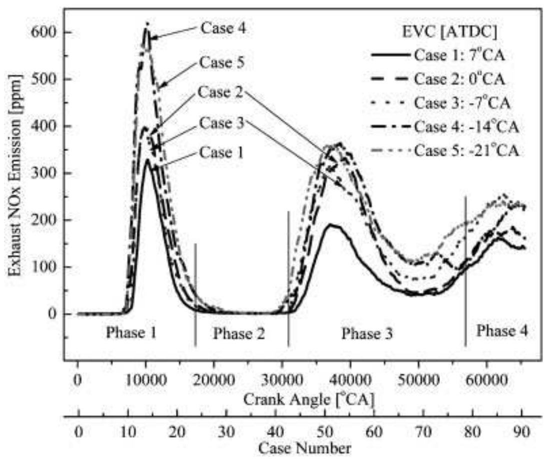

Fig. 1. NOx emissions during cold start [5]

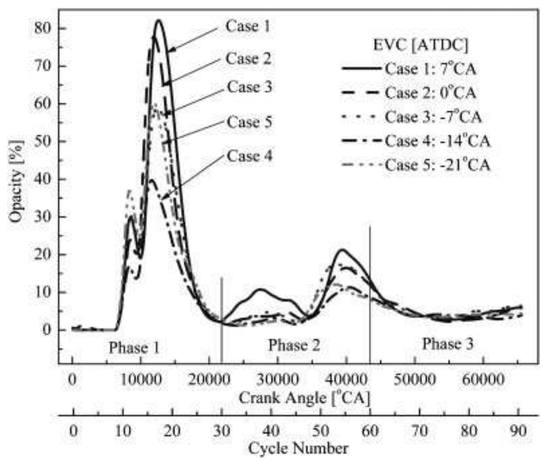

Fig. 2. Exhaust opacity during cold start [5]

Similarly, as shown in Fig. 1, NOx emission during cold start was divided into four phases, according to the characteristics of the NOx emission traces. During phase 1, NOx emission for every case first increased and then decreased, which corresponded to the increase and decrease in rail pressure. Obviously, the peak NOx emission appearing in this phase was caused by the overshoot rail pressure, which caused an increase in the cyclic delivery of fuel injection. In phase 2, when the rail pressure decreased to a certain degree, NOx emission for each case was reduced nearly to zero because combustion was unstable owing to the decrease in cyclic fuel delivery and worse mixing of the fuel and air. During phase 3, NOx emission increased and then decreased again owing to the variation in the rail pressure. However, the increment and decrement in this phase were much less than in the previous phases. During phase 4, NOx emission became stable gradually because the rail pressure and combustion process achieved steady state in this phase. As shown in Fig. 1, it was clear that the EVC timing had strong effect on NOx emission.

Figure 2 shows the opacity traces during cold start. The characteristics of opacity during the different phases of cold start were analyzed first. It can be seen that the EVC timing had significant effects on the opacity during cold start and especially on the peak opacity in phase 1. The whole process of the opacity trace was simply divided into three phases. Phase 1 is from cycle 1 to cycle 30, phase 2 from cycle 31 to cycle 60, and phase 3 from cycle 61 to cycle 91, [5].

OXYGEN-ENRICHED INTAKE AIR (OEA)

A membrane based oxygen-enriched intake air (OEA) method is proposed to improve in-cylinder combustion and then to reduce exhaust emissions during the start-up process. With OEA, the engine-out hydrocarbon, CO, and smoke emissions throughout the whole start-up process were all reduced considerably, but NOx emissions evidently increased, [4].

Papers [12, 13] show there is an evident increase in both, HC and CO emissions quickly following engine starting, and then they gradually decrease to the stable value. According to Bielaczyc and co-workers, [14, 15], the phase of cold start and warm-up has a considerable contribution to the entire exhaust emissions from diesel engines used in passenger cars. Ogawa and co-workers, [16,17], investigated the cycle-to-cycle transient characteristics of diesel emissions during starting and also found that the total HC and NOx emissions increase considerably to a maximum at about cycle 50 to cycle 200 after starting and then decrease to reach a steady value after about 1000 cycles [16, 17]. The EC 2000 regulations require a simultaneous engine cranking and bag sampling start as well as an additional low-ambient-temperature testing standard at -7^0C, which makes hard to meet further emission reduction. The following conclusions are drawn about the influences of OEA on the exhaust emissions during the start-up process of diesel engines, [4]:

-Smoke, HC, and CO emissions decreased with OEA throughout the start-up process. With 25 vol % OEA, the cumulative emissions during the initial 60 s of the start-up process were all reduced by over 50 per cent. However, more NO*x* emissions were produced than with the ambient air (AA). In particular, at 27 vol % oxygen concentration, the increase in NO*x* emissions doubled.

- With an oxygen concentration in the intake air, the percentage reduction in smoke, HC and CO emissions increased, but the reduction effect decreased with the increase in oxygen concentrations, especially from 25 to 27 vol %, while the increase in NO*x* emissions was significant. Therefore medium oxygen enrichment levels between 23 and 25 vol % are appropriate for actual application in view of the above emission effects with different oxygen concentrations. In order to evaluate further the effects of OEA on the exhaust emissions, the cumulative smoke, HC, CO, and NOx emissions are calculated by integrating the measured emissions data during the initial 60 s of the start-up process and a comparison of the results is shown in Fig. 3, [4].

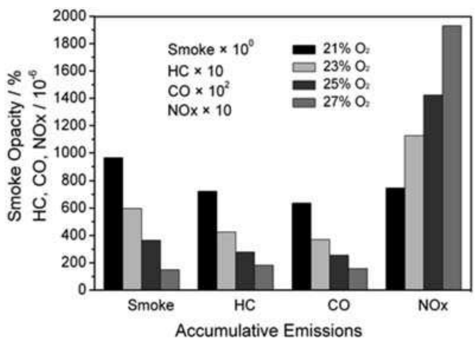

Fig.3 Cumulative smoke, HC, CO, and NOx emissions [4]

ALTERNATIVE FUELS

Emission legislation will be further tightened to reach ‘near zero’ emissions by the 2030 time frame. Due to the potential global warming, reductions of greenhouse gas (GHG) emissions by means of legislation is expected. This means that the efficiency of the combustion process must be improved or ‘near CO2-neutral’ fuels such as biomass-based fuels are to be employed.

Alternative fuel usage in road vehicles is becoming the more and more important, [18]. The world’s energy consumption continues to rise for mainly two reasons: the Earth’s population growth and the rising demand of energy in the developing countries.

The economies of the developed countries depend heavily on oil-based fuels. There have been many scenarios regarding oil reserves, production of fuels, the development of oil consumption, etc. which all affect the availability of oil-based fuels. One could say the time of cheap oil is over and, therefore, alternative fuels become more attractive. For these reasons, it is “certainly not too early” to consider the use of alternative fuels very seriously.[18]

Increased environmental awareness and depletion of fossil petroleum resources are driving industry to develop alternative fuels that are environmentally more acceptable. Transesterified vegetable oil derivatives called ‘biodiesel’ appear to be the most convenient way of utilizing bio-origin vegetable oils as substitute fuels in diesel engines. The methyl esters of vegetable oils do not require significant modification of existing engine hardware. Previous research has shown that biodiesel has comparable performance and lower brake specific fuel consumption than diesel with significant reduction in emissions of CO, hydrocarbons (HC), and smoke but slightly increased NO_x emissions, [19].

CONCLUSIONS

Diesel fuels have an important role in the industrial economy of any country. Because of the depletion of petroleum reserves, increasing fuel prices and uncertainties concerning petroleum availability, stringent emission standards and global warming caused by carbon dioxide (CO2) emissions, development of alternative energy sources and fuels has become increasingly important day by day.

This paper was designed as a bibliographic research upon the emissions recorded during cold start of diesel engines. Actually, this bibliographic study precedes the actions to be followed within the frame of a research project entitled “Research upon the development of a method to improve the cold starting of biodiesel engines for special destination vehicles”, which is granted by the Romanian Council for Scientific Research in the Higher Education (CNCSIS).

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