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The following component part numbers comprise the compilation report:
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[1]AUTOIGNITION, COMBUSTION INSTABILITY AND WHITE SMOKE UNDER TRANSIENT CONDITIONS with JP-8 FUEL

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SUMMARY

The goal of this project is to reduce the cold starting problems of military and commercial heavy-duty diesel engines, particularly the emission of white smoke. The failure of the autoignition process and/or combustion instability has been found to be the major causes of the cold starting problems. The approach is mainly experimental, supported be detailed analysis of the autoignition process. Models for the ignition delay period are developed considering the heterogeneity of the charge and the effect of piston motion during the ignition delay period. The maps developed for the stable combustion zone agreed fairly well with the experimental data. Also, the effect of diluents, such as exhaust gas recirculated into the fresh air (EGR) is experimentally investigated in two single-cylinder diesel engines. The effect of EGR on the global activation energy of the autoignition reactions is currently under investigation.

BACKGROUND

Cold starting problems in military and commercial diesel engines include the emission of large amounts of unburned fuel in the form of white smoke, hesitation, unreliable starting and complete failure of the engine to start. The current research showed that two factors contribute to such problems: a) failure of the autoignition process, and b) misfiring after starting due to combustion instability

EXPERIMENTAL WORK

Experiments were conducted in the cold room on a single-cylinder and a 4-cylinder heavy-duty diesel. The experiments covered two fuels: diesel fuel DF-2 used in the commercial sector and JP-8 fuel used in military vehicles. At normal room temperatures, combustion was unstable with JP-8, while it was stable with DF-2. At lower ambient temperatures, the engine failed to start on JP-8. With DF-2, combustion instability and white smoke increased with the drop in temperature.

The delayed start of combustion late in the expansion stroke has been found to cause the failure of the autoignitioin process. This indicated the low rates of the autoignition reactions resulting in fairly long ignition delays.

IGNITION DELAY

In order to develop strategies for successful autoignition, injection timing need to be advanced to account for the increase in the ID. A correlation is needed to account for the increase in ID due to the drop in temperature and piston motion during the expansion stroke. The commonly used correlation accounts for the change in temperature, and is only suitable for ignition in a constant volume environment.

$$\tau_{id} = Ap^{-n} \exp\left(\frac{E_A}{\tilde{R}T}\right)$$

Where p: pressure, E_A : global activation energy, $\tilde{R}$: universal gas constant and T: absolute temperature.

A NEW IGNITION DELAY FORMULATION

A new correlation is developed in this program for dF-2 to account for the change in the cylinder volume V during ID:

$$\frac{dX}{dt} = 0.876 p^{1.899} e^{-\frac{4665}{T}} - \frac{X}{V}\frac{dV}{dt}$$

X is the ratio of the chain carriers produced at any time t divided by the critical concentration of the chain carriers. In this model, autoignition is assumed to occur when the concentration of the chain carriers reaches a critical value.

PREDICTION OF MISFIRING ZONE BOUNDARIES

The ID, in crank angle degrees, is calculated for DF-2, at an ambient temperature of 20°C, at different injection timings as shown in the figure. The injection timing for minimum ID occurs earlier before TDC as the speed increases. Retarding the injection beyond a certain point results in complete misfiring. This is caused by the drop in the gas temperature during the expansion stroke and the resulting slowing down of the autoignition reaction rates. The analysis indicated that misfiring occurs at an earlier injection timing at higher speeds. Figure (1) shows the boundaries of the misfiring zone, predicted by the theoretical analysis.
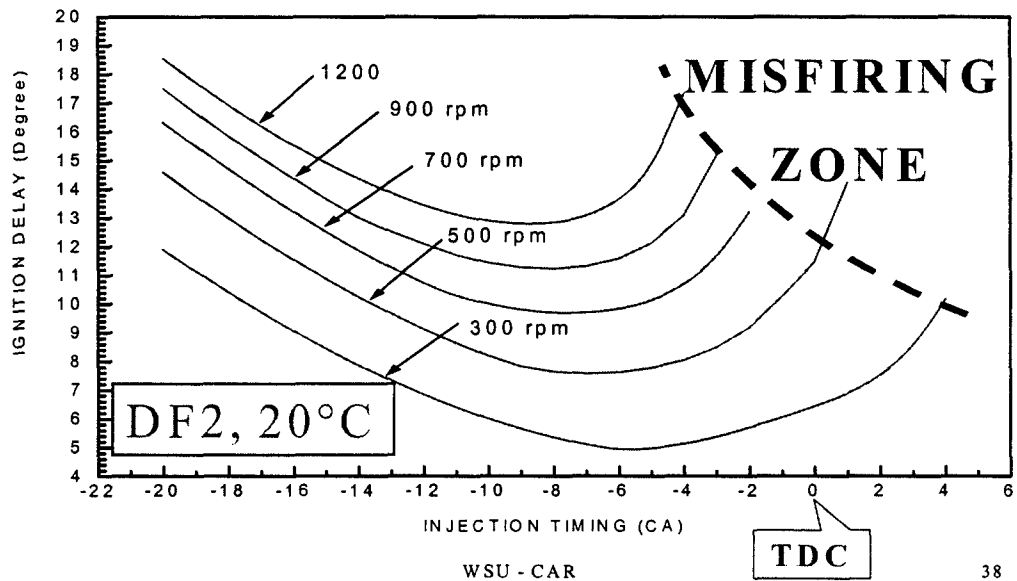
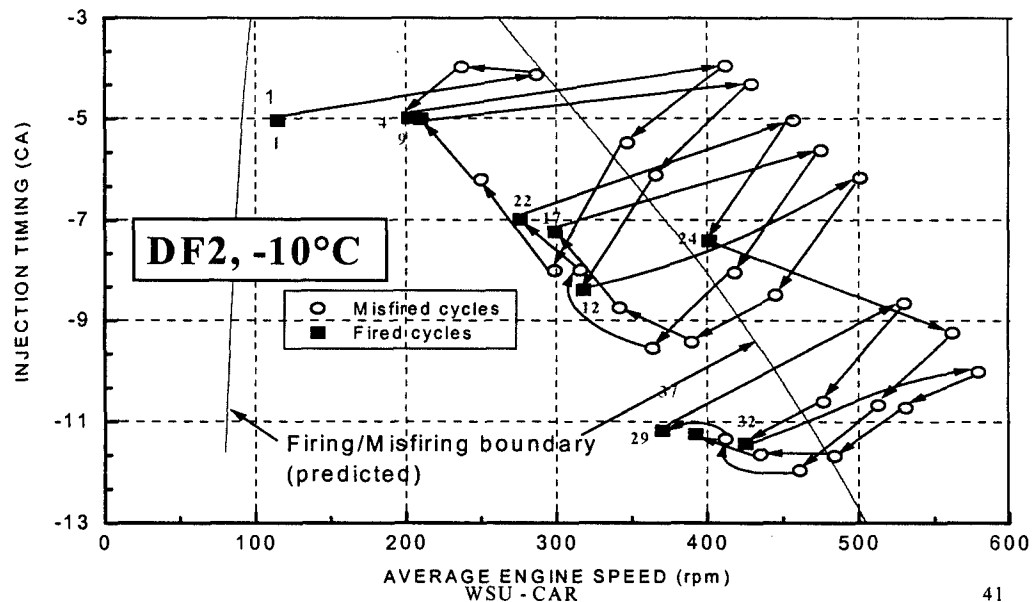Figure 1. Effect of injection timing on ignition delay and misfiring zone

Figure 2. Comparison between the predicted and experimental misfiring cycles.

114

COMPARISON BETWEEN PREDICTED MISFIRING ZONE AND ACTUAL ENGINE DATA

Figure (2) shows the predicted misfiring boundary and the actual injection timing of the 4-cylinder engine during the first 37 cycles of the starting transient at -10°C. It can be noticed that the misfiring boundary lies at the center of a band of injection timings and engine speeds. The engine moved from the firing zone to the misfiring zone many times. The majority of the misfiring cycles lie in the predicted misfiring zone. The trend is misfiring occurs as the engine accelerates after firing. Because of misfiring, the engine decelerates to a lower speed in the firing zone and fires again. This explains the unstable combustion observed during cold starting of diesel engines.

PAPERS PUBLISHED FROM THIS RESEARCH PROJECT
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2. "A New Ignition Delay Formulation with Predictions of Diesel Engine Cold Start Misfiring," Zhiping Han, Naeim A. Henein and Walter Bryzik, SAE Paper No. 2000-01-1184, SP-1533, pp 175-184, 2000.
3. "Combustion and Emission Characteristics of a single-cylinder HSDI Diesel Engine," N. A. Henein, M-C. Lai, D-H Wang and Paul Miles, Central State Section/The Combustion Institute, Indianapolis, IN, April 16-18, 2000.
4. "Diesel Cold Start Combustion Instability and Control Strategy," Zhiping Han, Naeim Henein, Bogdan Nitu and Walter Bryzik, SAE Paper No. 2001-01-1237.
5. " Emissions Trade-Off and Combustion Characteristics of a High-Speed Direct Injection Diesel Engine," Naeim A. Henein, Ming-Chia Lai, Inderpal Singh, Dahai Wang and Liang Lui, SAE Paper No. 2001-01-0197.

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i