TECHNICAL BULLETIN

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FPC/FTC CATALYTIC ACTION THEORY

1. Diesel Combustion Theory

1.1 The Combustion Process

The four-cycle compression-ignition engine employs the conventional four strokes per power cycle of intake, compression, power and exhaust. The two-cycle engine shortens the number of strokes of the piston by combining the power and exhaust stroke and the intake and compression stroke.

The air inducted on the intake is either normally aspirated or forced in by the supercharger while the fuel is injected into the cylinder near the end of the compression stroke. In most diesel engines the combustion chamber temperature at the end of the compression stroke is approximately 600 degrees C (Celsius). This temperature is dependent upon the compression ratio and the initial air temperature.

Near the end of the compression stroke, fuel is sprayed into the combustion chamber at pressures varying from about 1,200 psi to over 30,000 psi. The injection pressure is governed by engine speed and size and by the type of combustion chamber and injection system used.

With the commencement of fuel injection the combustion process is initiated. Each charge of injected fuel experiences several phases in the reaction as follows:-

(1) An ignition delay period.

(2) A period of rapid combustion.

(3) A period of combustion where the remainder of the fuel charge is burned as it is injected.

(4) An after burning period in which the unburned fuel may find oxygen and burn, often times referred to as the tail of combustion.

In following the combustion process and the path of fuel particles it should be understood that after ignition has occurred many of these steps will be proceeding at the same time since the mixture is homogenous.

1.2 The Delay Period

The delay consists of a physical and a chemical delay. The physical delay is required to atomise the fuel, mix it with air, vaporise it and produce a mixture of fuel vapour and air.

During the chemical delay, preflame oxidation reactions occur in localised regions with temperature increase of 540 to 1100 degrees C. These preflame reactions are initiated by the catalytic effect of wall surfaces, high temperatures and miscellaneous particles that form the active chain carriers prior to rapid combustion. As the local temperature increases the fuel vapours begin to crack at an accelerated rate and produce material with high percentages of carbon which become heated to incandescence as local ignition is initiated.

Inflammation develops quickly either by rapid and complete oxidation of the fuel and air or the oxidation of the intermediate products of the chain reactions of the fuel.

1.3 The Period of Rapid Combustion

Combustion during the period of rapid combustion is due chiefly to the burning of fuel that has had time to vaporise and mix with air during the delay period. The rate and extent of the burning during this period are closely associated with the length of the delay period and its relation to the injection process.

The relation of the delay on both the rate and extent of pressure rise during this phase is especially strong when the delay period is shorter than the injection period.

1.4 The Third Phase of Combustion

The third phase is the period from maximum pressure to the point where combustion is measurably complete.

When the delay period is longer than the injection period the third period of combustion will involve only the fuel that has not found the necessary oxygen during the period of rapid combustion. In this case only the mixing process limits the combustion rate. However, even when all the fuel is injected before the end of the delay period, poor injection characteristics can extend the third period well into the power or expansion stroke causing low output and poor efficiency.

When injection timing is such that the second phase of combustion is complete before the end of injection, some portion of the fuel is injected during the third phase and the rate of burning will be influenced by the rate of injection as well as by the mixing rate.

1.5 The Final Phase of Combustion.

The final phase, or tail of combustion, continues after the third phase at a diminishing rate, as any remaining fuel and oxygen are each consumed. Diffusion combustion with production and combustion of carbon particles and a high rate of heat transfer radiation characterise this last stage and the previous one. This phase occurs well down the expansion stroke when much of the oxygen has been consumed and combustion temperatures are lower. It is at this stage that smoke and carbon monoxide emissions are formed.

1.6 The Ideal Combustion Process

The thermal efficiency of an internal combustion engine, whether spark or compression-ignition, will increase if the combustion time is reduced. Thus, more work can be extracted from the same energy input from combustion. The rate of pressure rise during the period of rapid combustion corresponding to constant volume combustion should be as rapid as possible without exceeding a certain value.

The fuel remaining after the period of rapid pressure rise should be burned at a rate such as to hold the cylinder pressure constant at the maximum allowable value until all the fuel is burned.

1.7 The Effects of Operating Conditions on Combustion

With respect to the diesel engine the combustion rate as well as the rate and extent of pressure rise depends greatly on the design of the combustion chamber and the injection system. However, injection timing, engine speed, turbulence, compression ratio, fuel air ratio, spray characteristics, fuel cetane number and inlet temperature and pressure all affect the combustion rate or flame speed.

2. Possible Mode of Action of the FPC/FTC Combustion Catalyst

2.1 Flame Propagation

As previously mentioned, the speed with which the combustion process takes place influences the efficiency of the heat released by the chemical reaction. With greater rates of heat release it is often possible to transfer more of the heat into useful energy.

The combustion catalyst manufactured by Fuel Technology Pty Ltd is a burn rate modifier. When the combustion catalyst is introduced into a liquid hydrocarbon fuel and combustion begins the catalyst appears to form propagating centres that initiate multiple flame fronts. These propagating centres in effect increase the thermal conductivity of the fuel-air mixture since heat transmission through it is more rapid with their presence. The effect appears to be most profound during the mixing-controlled and final phase of combustion when flame propagation is slowed or controlled by the rate at which fuel and air can mix to combustible proportions. The combustion catalyst assists in maintaining flame speed through the third and last phase of combustion.

The completeness of combustion may also be positively affected. If combustion is more complete more energy is released while the flame front traverses through the fuel-air mixture. **Controlled engine tests with FPC/FTC catalyst reveal not only increased horsepower output and reduced fuel consumption but also typically reduced unwanted gaseous and particulate exhaust emissions.**

Further, when engine operating conditions are such that flame speed is slowed creating greater combustion time losses, the FPC/FTC catalyst will recover a greater percentage of those losses. Thus the catalyst will have a more profound effect upon engines operating in the field than engines operating in the laboratory.

3. Laboratory and Stationary Engine Tests

3.1 The AAR RP-503

In early 1992, FPC/FTC was submitted to the Association of American Railroads (AAR), Recommended Practice 503 (RP-503) test at the Southwest Research Institute (SwRI), San Antonio, Texas, USA.

The RP-503 constitutes two screening tests and an engine performance trial. The screening tests include the determination of the additive effect upon fuel properties, engine deposit formation and engine wear. The final procedure is an engine performance trial conducted in a 12-cylinder, 645E3B EMD locomotive engine.

These studies concluded that FPC/FTC catalyst had no measurable effect on the chemical properties of the fuel, nor did it detrimentally impact engine life and deposit formation. The EMD engine also showed a 1.74% improvement in bsfc at a 95% confidence level with FPC/FTC catalyst treated fuel.

This is a remarkable improvement given the existing efficiency of this particular engine (37.2% brake thermal efficiency and 0.354 bsfc) and the fact the test engine was run under optimum engine conditions (steady-state, notch 8, 900 rpm). Under these conditions injection timing is the best match for maximum horsepower and lowest bsfc and, therefore, combustion time losses are minimised. Further, the engine was in like-new condition and smoke emissions were nil.

The AAR specifies these engine test conditions since a typical locomotive engine operates 50 to 60% of the time at notch 8. However, the steady state, maximum horsepower operating conditions tend to minimise the potential for horsepower and bsfc gains.

3.2 The WAIT Study

Studies by the Western Australian Institute of Technology (WAIT) have collected considerable data demonstrating the effect of the FPC/FTC catalyst on engine efficiency while operating at varying rpm, load and injection timing. The test was designed to best illustrate the effects of the combustion catalyst. In addition, the test conditions were meant to relate the effect of the catalyst, to the most commonly altered settings and conditions encountered, during normal field operation of a heavy-duty compression-ignition engine.

The objective of the WAIT study was to analyse the effect of the combustion catalyst on engine brake power and brake specific fuel consumption. In order to considerably broaden the scope of the test program in terms of relevance to simulating true commercial and industrial operating conditions, the following parameters were introduced to be varied accordingly:

(1) Engine speed
(2) Throttle setting
(3) Fuel injection timing
(4) The concentration of the catalyst in the diesel fuel;

The manner in which each parameter was altered is described below;

- Engine speed in all tests was varied from 1600 rpm to 2400 rpm by increments of 200 rpm.
- Throttle settings were altered alternatively from half throttle to full throttle in the majority of the tests.
- Fuel injection timing was varied from 18 degrees before top dead centre (BTDC) to 42 degrees BTDC in increments of 6 degrees in specific tests. The standard injection timing was 30 degrees

BTDC.

- The concentration of the catalyst in the diesel fuel was altered by employing three different mixing ratios.

3.3 Conclusions from WAIT Study

The Varimax engine test program has shown quite convincingly the benefits of FPC/FTC catalyst in diesel fuel. At the highest catalyst concentration in the fuel, bsfc improvements ranged from 1.71% to 4.99%.