CONTROLLING COMBUSTION IN HCCI DIESEL ENGINES

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ABSTRACT – HCCI is an alternative piston-engine combustion process that can provide efficiencies as high as compression-ignition, direct-injection (CIDI) engines (an advanced version of the commonly known diesel engine) while, unlike CIDI engines, producing ultra-low oxides of nitrogen (NO_x) and particulate matter (PM) emissions. HCCI engines operate on the principle of having a dilute, premixed charge that reacts and burns volumetrically throughout the cylinder as it is compressed by the piston. In some regards, HCCI incorporates the best features of both spark ignition (SI) and compression ignition (CI),

In the high speed direct injection Diesel engines the ignition delay is a critical parameter for controlling air-fuel mixing and combustion processes.

In this paper are presented the theoretically and experimentally results of the studies develops in Automotive and Engines Department of University TRANSILVANIA Braşov for design of a new pilot injection system that makes possible the control of Homogeneous Charge Compression Ignition in a conventional D. I. Diesel engines, with application in design and manufacture of Diesel engines for truck.

INTRODUCTION

A major advantage of HCCI combustion is its fuel-flexibility. Because HCCI engines can be fueled with gasoline, implementation of HCCI engines should not adversely affect fuel availability or infrastructure. (CIDI engines cannot be operated with gasoline due to its low cetane number.)

“With successful R&D, HCCI engines might be commercialized in light-duty passenger vehicles by 2010, and by 2015 as much as a half-million barrels of primary oil per day may be saved” [2].

Additional savings may accrue from reduced refining requirements for fuels for HCCI engines relative to gasoline for conventional SI technology.

In addition to gasoline, HCCI operation has been shown for a wide-range of other fuels. Due to this fuel-flexibility, some HCCI applications (e.g., light-duty vehicles) could use gasoline, while other HCCI applications (e.g., heavy-duty trucks) could use diesel fuel.

HCCI also has advantages as a potential low emissions alternative to CIDI engines in light-medium and heavy-duty applications. Even with the advent of effective exhaust emission control devices, CIDI engines will be seriously challenged to meet the future environmental protection standards. Moreover, CIDI emission control technologies are unproven, expensive, require the injection of fuel or other reductants into the exhaust stream for NO_x reduction, and currently do not last the life of the engine. These emission control systems would also require the use of more expensive ultra-low-sulfur fuels (less than 15 ppm). In addition to emission control devices, expensive fuel injection equipment will be necessary to control emissions (some estimate fuel injection equipment will account for one-third of engine costs).

Although the actual cost and fuel-consumption penalties of CIDI emission controls are uncertain, the use of HCCI engines or engines operating in HCCI mode for a significant portion of the driving cycle could significantly reduce the overall cost of operation, thus saving fuel and reducing the costs of lowering emissions.

As an alternative high-efficiency engine for light-duty vehicles, HCCI has the potential to be a low emissions alternative to CIDI and SIDI engines. Intensive efforts are underway to develop CIDI and SIDI engines for automotive applications to improve overall vehicle fuel efficiency; however, both CIDI and SIDI engines face several hurdles.

SIDI engines needs more efficient devices to operate lean. Consequently, NO_x emission control devices similar to those being developed for CIDI engines are required. In addition, the sulfur content of gasoline will be 30 ppm average and 80 ppm maximum as specified actual vehicle emission standards, a level that may be too high for the long term durability of lean NO_x emission control systems.

While HCCI engines have several inherent benefits as replacements for SI and CIDI engines in vehicles with conventional powertrains, they are particularly well suited for use in internal combustion (IC)-engine/electric series hybrid vehicles. In these hybrids, engines can be optimized for operation over a fairly limited range of speeds and loads, thus eliminating many of the control issues normally associated with HCCI, creating a highly fuel-efficient vehicle.

In addition to the on-highway applications discussed above, it should be noted that the benefits of HCCI engines could be realized in most other internal combustion engine applications such as off-road vehicles, marine applications, and stationary power applications.

HCCI combustion is achieved by controlling the temperature, pressure and composition of the air/fuel mixture so that it autoignites near top dead center (TDC) as it is compressed by the piston. This mode of ignition is fundamentally more challenging than using a direct control mechanism such as a spark plug or fuel injector to dictate ignition timing as in SI and CIDI engines, respectively. While HCCI has been known for some twenty years, it is only with the recent advent of electronic

engine controls that HCCI combustion can be considered for application to commercial engines.

Even so, several technical barriers must be overcome before HCCI engines will be viable for high-volume production and application to a wide range of vehicles.

The following describes a way for developing practical HCCI engines for transportation.

CONTROLLIG COMBUSTION BY IGNITION DELAY

The ignition delay in a Diesel engine was defined as a time (or crank angle) interval between the start of injection and the beginning of combustion. The start of injection is usually taken as the time when the injector needle lifts off its seat (determined by a needle-lift sensor). The start of combustion is more difficult to determine precisely. It is best identified from the change in slope of the heat-release rate, determined from cylinder pressure data. Depending on the character of the combustion process, the pressure data alone may indicate when pressure change due to combustion first occurs. Flame luminosity detectors are also used to determine the first appearance of the flame. Experience has shown that under normal conditions, the point of appearance of the flame is later than the point of pressure rise and results in greater uncertainty or error in determining the ignition point. Conventionally, in the D. I. Diesel engines, the beginning of combustion correspond of the point of the pressure-angle diagram at the in cylinder pressure curve (with combustion) on detach of the cylinder pressure curve without combustion.

Since the ignition characteristics of the fuel affect the ignition delay, this property of a fuel is very important in determining Diesel engine operating characteristics such as conversion efficiency smoothness of operation, misfire, smoke emissions, noise and ease of starting.

The ignition quality of a fuel is defined by its cetane number. For low cetane fuels with too long an ignition delay, most of the fuel is injected before ignition occurs, which results in very rapid burning rates once combustion starts with high rates of pressure rise and high peak pressures. Under extreme conditions, when autoignition of most of the injected fuel occurs, this produce an audible knocking sound, often referred to as "Diesel knock".

For higher cetane number fuels, with shorten ignition delays, ignition occurs before most of the fuel is injected. The rates of heat release and pressure rise are then controlled primarily by the rate of injection and fuel-air mixing, and smoother engine operation results.

A homogeneous fuel mixing process in D. I. Diesel engines can be provide by adding a part of fuel in intake stroke. This can realize a homogenization of air-fuel mixture in the last part of compression stroke. Practically, the principal part of fuel doze is inject in a homogeneous mixture, that affect the velocity of the first chemical reactions of ignition.

The new injection system develop in Automotive and Engine Department Laboratory, called **Pilot Injection Via Intake Valve Seat**, introduce a fraction of fuel doze per work cycle and per cylinder in the minimally air flow section offered at opening of the intake valve. In this section, the air flow velocity attains an absolute maximum and can such obtaining the better atomization and vaporization of fuel pilot droplets for a homogeneous air-fuel mixing.

For a standard single cylinder Diesel engine and for three different advance angles of principal injection (IPA 1, IPA 2, IPA 3) was measuring the same parameter of engine with new pilot injection system.

Conventionally, in the D. I. Diesel engines, the beginning of combustion correspond of the point of the pressure-angle diagram at the in cylinder pressure curve (with combustion) on detach of the cylinder pressure curve without combustion that permit to determine the ignition combustion delay when on know the advance angle of injection.

The variation of cylinder pressure in the three cases (with combustion and without combustion) is indicated in figures 1, 2 and 3.

For the first advance angle the data system was called IPA 1, for the second IPA 2 and for the third IPA 3. For the standard Diesel engine (without pilot injection system) the file of data was called MS.

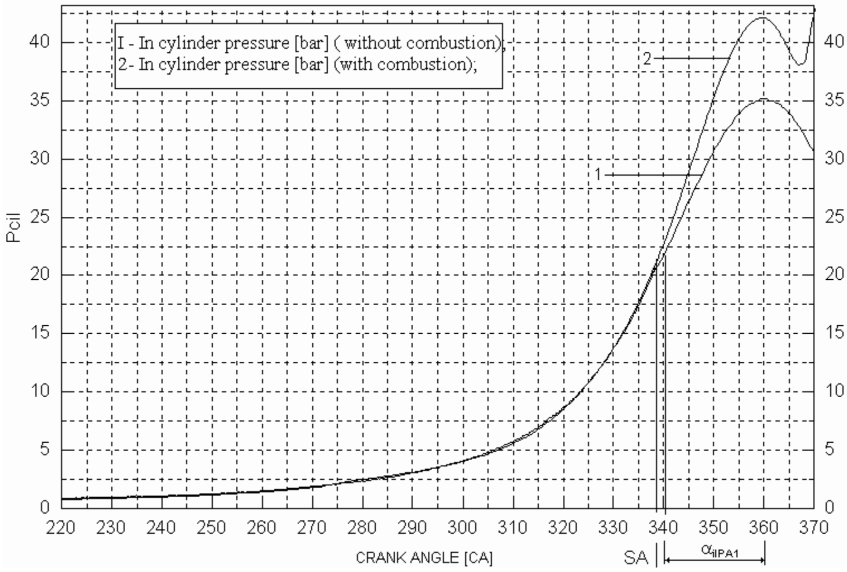

Fig.1 Experimental determination of ignition delay (IPA 1 case). SA- start of main ignition; $\alpha_{IPA\ 1}$- angle of advance of main injection.

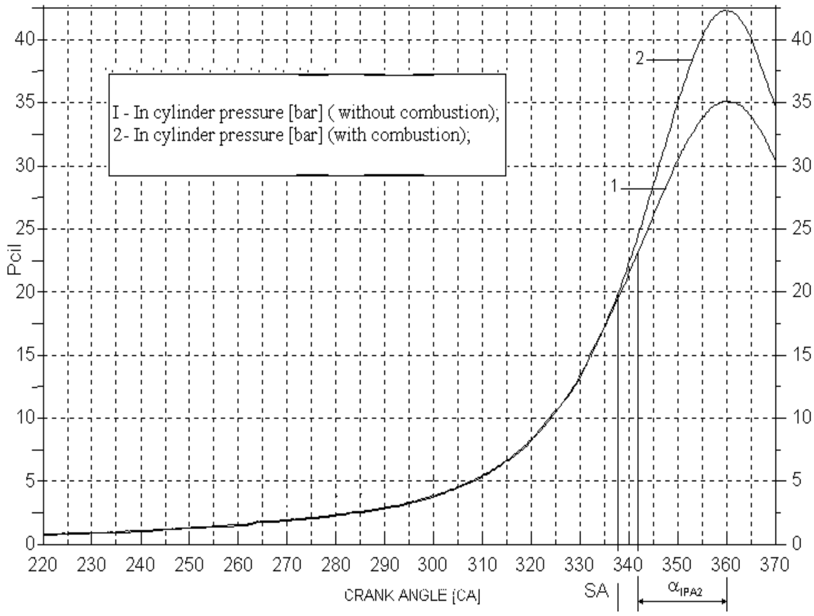

Fig. 2 Experimental determination of ignition delay (IPA 2 case). SA- start of main ignition; $\alpha_{IPA\ 2}$- angle of advance of main injection.

The experimentally results show that, in particular condition, the ignition process in D. I. Diesel engine with **Pilot Injection Via Intake Valve Seat** can be provide by the premixed fuel-air mixture (assuming as homogenous) formed in intake stroke by air and pilot fuel fraction.

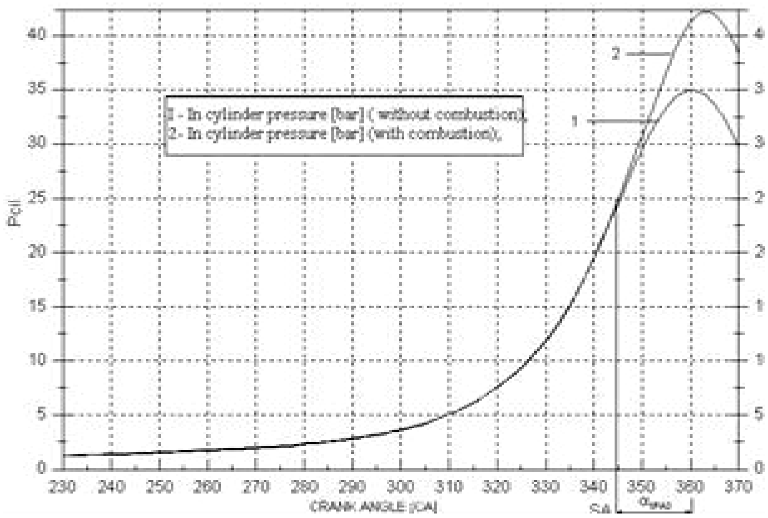

Fig. 3 Experimental determination of ignition delay (IPA 3 case). SA- start of main ignition; $\alpha_{IPA\ 3}$- angle of advance of main injection.

In these conditions, the ignition delay period, relative at start of principal injection process, can be a negative amount.

This effect of new pilot injection system has a maximum consequence for controlling combustion in high speed HCCI Diesel engines.

For the cases showed before, the amounts of ignition delay are indicating in Table 1.

Table 1 Amounts of "ignition delay"

	IPA 1	IPA 2	IPA 3
Ignition delay (experimentally) [CA] (Main injection reference)	-4,3	-5,6	0

The negative values of ignition delay, determinates relative to main injections, demonstrate that ignition of a homogeneous air-fuel charge occurs before start of main injection.

HEAT RELEASE SHAPE AND HCCI CONTROLLING PROCESS

For the second cases showed on the top the experimental and calculated variation are indicates in figure 4.

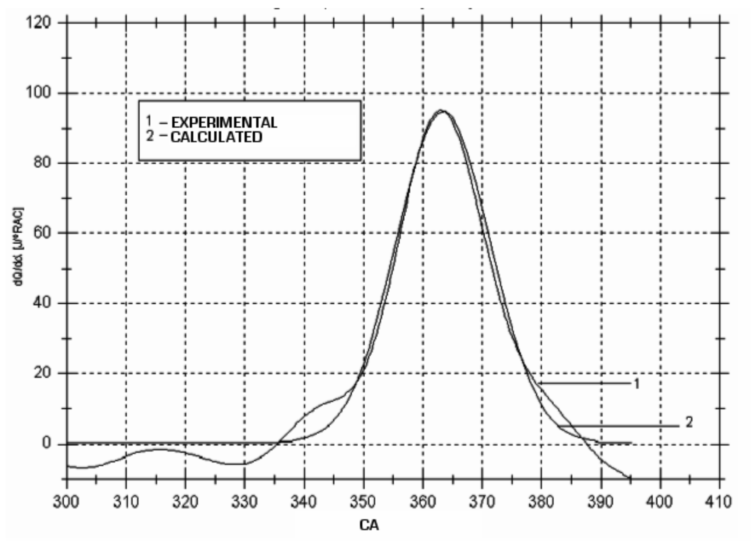

Fig. 4 Experimental and calculated heat release.

It can observe that the heat release shape is similar to S. I. engine that indicate combustion into homogeneous air fuel mixture.

CONCLUSIONS

1. HCCI combustion management is achieved by controlling the temperature, pressure and composition of the air/fuel mixture so that it autoignites near top dead center (TDC) as it is compressed by the piston. This mode of ignition is fundamentally more challenging than using a direct control mechanism such as a spark plug or fuel injector to dictate ignition timing as in SI and CIDI engines, respectively.

While HCCI has been known for some twenty years, it is only with the recent advent of electronic engine controls that HCCI combustion can be considered for application to commercial engines.

2. The experimentally results show that, in particular condition, the ignition process in D. I. Diesel engine with **Pilot Injection Via Intake Valve Seat** can be provide by the premixed fuel-air mixture (assuming as homogenous) formed in intake stroke by air and pilot fuel fraction.

3. In these conditions, the ignition delay period, relative at start of main injection process, can be a negative amount.

4. This effect of pilot injection system can have a maximum consequence on control a HCCI processes in Diesel engines.

REFERENCES

(1) ZAIDI, K., ANDREWS, G. E., GREEN-HOUGH J. H. *Diesel Fumigation Partial Premixing for Reducing Ignition Delay and Amplitude of Pressure Fluctuation* SAE, SP 1326, 980535, 1998, p. 207 - 215.

(2) RYAN III,T., CALLAHAN, T. *Homogeneous Charge Compression Ignition of Diesel Fuel* SAE, SP 1179, 961160, 1996, p.157 - 166.

(3) ISPAS, N. *Researches on a new concept concerning combustion control in high performance D. I. Diesel engines* -PHD thesis, 1999, Braşov.

(4) COFARU,C., ISPAS,N., CONSTANTI-NESCU,B., *Effect of fuel air mixture preparation on combustion process and energetic parameters and exhaust emission in a D.I. Diesel engine* - Proceedings of 1st International Conference on “Control and diagnostic in automotive application”, Genova, Italy, 1996, p.533-542.

(5) HUA ZHAO *HCCI and CAI Engines for the Automotive Industry,* WOODHEAD PUBLISHING LIMITED, Cambridge, 2007, England.