THE INFLUENCE OF THE EGR RATE ON A HCCI ENGINE MODEL CALCULATED WITH THE SINGLE ZONE HCCI METHOD

Radu Cosgarea*, Corneliu Cofaru, Mihai Aleonte

Transilvania University of Brasov

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ABSTRACT - Due to the more restrictive standards of pollution and to the necessity to combine the main advantages of the gasoline engines (the homogeneous charge) with the main advantages of the diesel engines (higher compression ratios which determinates higher efficiencies) the homogeneous charge compression ignition (HCCI) engines were developed. One of the major challenges is to control the start of the combustion. The exhaust gas recirculation is the most common method used to control the HCCI combustion.

A diesel HCCI engine model was developed to study the effects of the EGR on the combustion characteristics. The HCCI engine model is made from two system boundaries, one air cleaner, three intake pipes, two plenums, one cylinder, three exhaust pipes and the one catalyst. The mixture formation is external. The tests were made for four different operating points, keeping the engine speed constant and increasing the EGR from 0 to 60%.

This paper presents the influence of the EGR on the cylinder pressure, cylinder temperature, heat release rate and mass fraction burned. Due to the two stage combustion characteristic to the HCCI engines, two peaks appear on the heat release rate diagram, one corresponding to the low temperature oxidation and the other to the high temperature oxidation. With increasing EGR the ignition delay increases and the cold flame and main ignition can not be distinguished any more on the heat release rate. Another effect of the EGR is the reduction of the cylinder temperature. Using different EGR rates, the maximum temperature was reduced with more than 500 K. A lower temperature leads to lower nitrous oxides emissions.

INTRODUCTION

The homogeneous charge compression ignition (HCCI) engines were developed to combine the advantages of the spark ignition engines with the advantages of the compression ignition engines. The result is an engine with low raw emissions and high fuel economy. The compression ratio is similar to the diesel engines with benefits on the fuel consumption. The load is controlled modifying the quality of the mixtures. The fuel is homogenized before the combustion, so there are no zones which rich mixtures, which leads to lower soot emissions. Due to the high air excess ratio the temperatures from inside the cylinder are lower, which leads to lower nitrous oxides emissions.

Different strategies were used to obtain the homogeneous combustion. The first tests were made using two-stroke engines (6). Many names were used, Active Thermo-Atmosphere Combustion (ATAC) (6), Premixed Lean Diesel Combustion (PREDIC) (7), Uniform Bulky Combustion System (UNIBUS) (8), Controlled Auto-Ignition (CAI) (5), but in the last period the acronyms HCCI are used.

Due to the homogeneous charge and to the compression ignition, the combustion is almost simultaneous in all the charge. The burning speed is lower than in the conventional engines, but because the whole mixture is burning at the same time, the heat release is shorter. The

HCCI engines can work only at partial loads. Because the mixture is homogeneous and the load is controlled modifying the quality of the charge, at very low loads the mixture is too lean to burn. At very high loads, the heat release rate is increasing too high and the engine is operating like a spark ignition engine which is knocking.

THE HCCI ENGINE MODEL

The HCCI engine model is presented in figure 1.

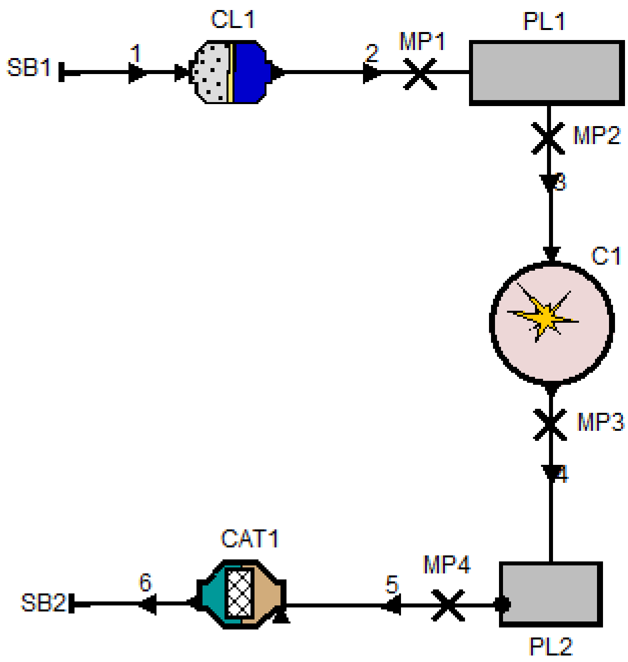

Figure 1. The HCCI engine model

The HCCI engine model is made from the system boundaries SB1 and SB2, the air cleaner CL1, the intake pipes 1, 2, 3, the plenums PL1 and PL2, the cylinder C1, the exhaust pipes 4, 5, 6 and the catalyst CAT1. Four measuring points are used, two on the intake pipes (one between the air cleaner CL1 and the plenum PL1 and the other between the plenum PL1 and the cylinder C1) and two on the exhaust pipes (one between the cylinder C1 and the plenum PL2 and the other between the plenum PL2 and the catalyst CAT1).

The mixture, which is made from air, fuel and exhaust gases, is formed outside the system boundary SB1. It enters through the system boundary SB1 and enters from the pipe 1 in the air cleaner CL1. The air cleaner is used only to simulate the gasodynamic losses and the pressure drop over depending on the gas flow from the intake circuit. The mixture is passing through the pipe 2, enters in the plenum PL1 and afterwards is entering in the cylinder through the pipe 3. The mixture is burned inside the cylinder and the exhaust gases are eliminated through the pipe 4, plenum PL2, pipe 5, catalyst CAT1, pipe 6 and system boundary SB2. The catalyst is used only to simulate the gasodynamic losses and the pressure drop over depending on the gas flow from the exhaust circuit.

The engine specifications are shown in table 1.

Engine type	HCCI
Fuel	Diesel
No. of cylinders	1
Compression ratio	18:1
Displacement [cm^3]	651,55
Bore [mm]	100
Stroke [mm]	83
Con-rod length [mm]	200
No. of valves	4 (2 for admission, 2 for exhaust)

Table 1. Engine specifications

THE COMBUSTION ANALISYS

The tests were made for four different operating points. For each operating point the parameters were measured during 100 cycles. The engine speed is maintained constant at 1750 rpm (revolutions per minute). The EGR (exhaust gas recirculation) rate is 0 for the first operating point and then is increased to 20%, 40% and 60%. The main objective of the tests is to observe the influence of the EGR on the homogeneous combustion. The pressure traces, the cylinder temperature, the heat release rate and the mass fraction burned are the tools used to evaluate the combustion.

Figure 2 shows the influence of the EGR rate on the cylinder pressure.

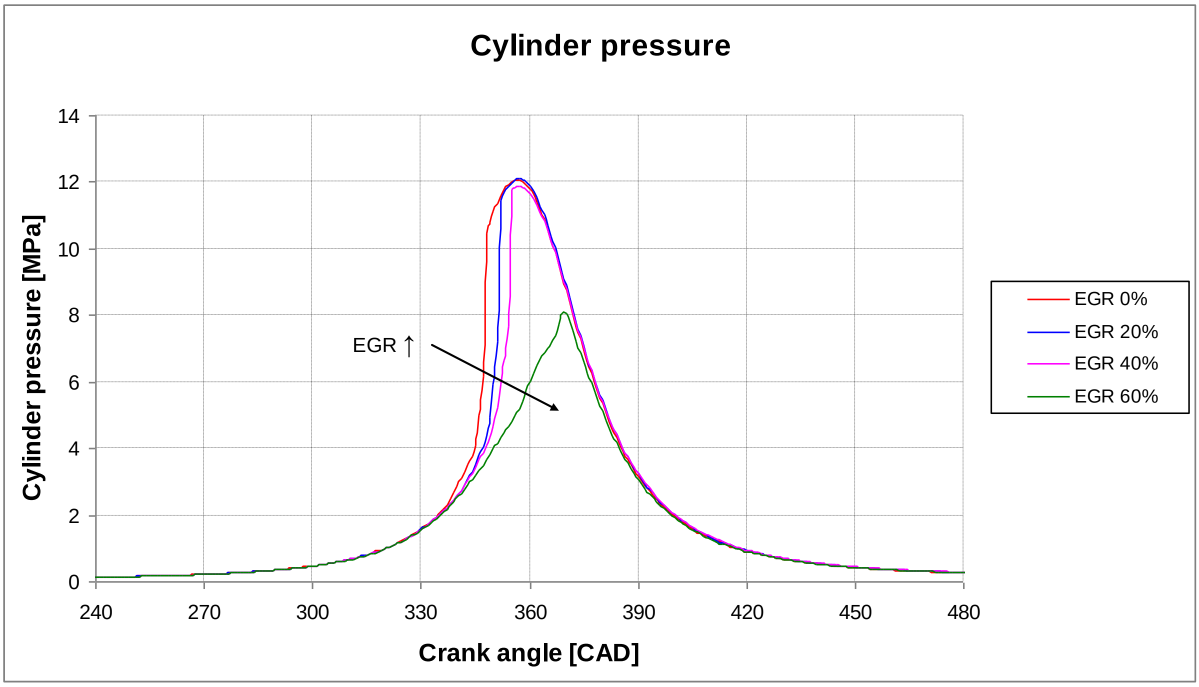

Figure 2. The influence of the EGR on the cylinder pressure

The cylinder pressure trace is a very important tool for understanding the combustion. The cylinder pressure trace enables to evaluate some thermo-dynamical data for the combustion analysis like the heat release rate and the combustion temperature, which can not be measured directly (3).

The results show that the maximum pressure is decreasing when the EGR is increasing. When the amount of EGR is increased slightly (20%, 40%), the differences are small. When very high EGR rates are used (60%), the maximum pressure drops very fast. When the EGR is increasing, the maximum values are obtained at a higher crank angle position.

The temperature from inside the cylinder is very important due to its influence on the formation of nitrous oxides (NOx) emissions. The main benefit of the HCCI combustion is the reduction of NOx raw emissions up to 90–98% in comparison with conventional combustion (2).

In figure 3 we can observe the influence of the EGR on the cylinder temperature. The evolution is similar with the cylinder pressure evolution. Higher EGR rates determine lower maximal temperatures and higher crank angle positions where these values are obtained.

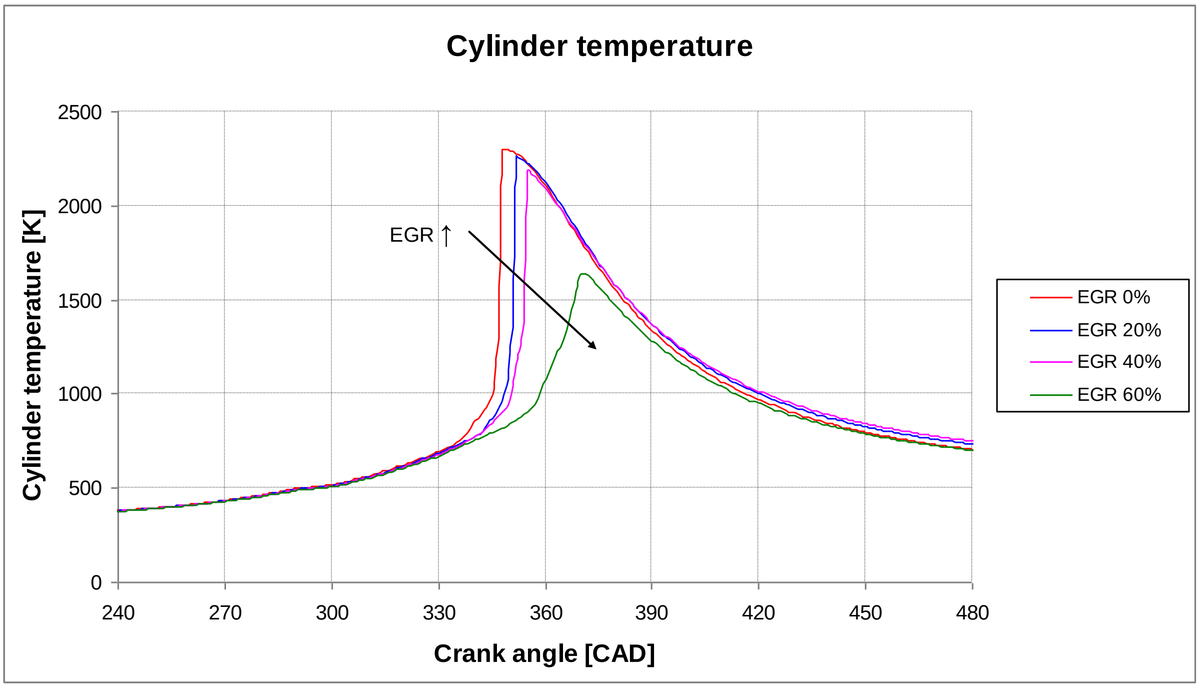

Figure 3. The influence of the EGR on the cylinder temperature

The combustion in the HCCI engines is almost simultaneous in all the charge. This leads to very high values of the heat release rate, which are limiting the engine's operating range. EGR is used to enlarge the combustion duration to avoid the extreme values of the heat release rates (1).

Figure 4 shows the influence of the EGR on the heat release rate. It can be observed that the first peak, corresponding to the low temperature oxidation is disappearing when the EGR is increasing. The heat release is starting later, it takes a longer time and the maximum values are lower.

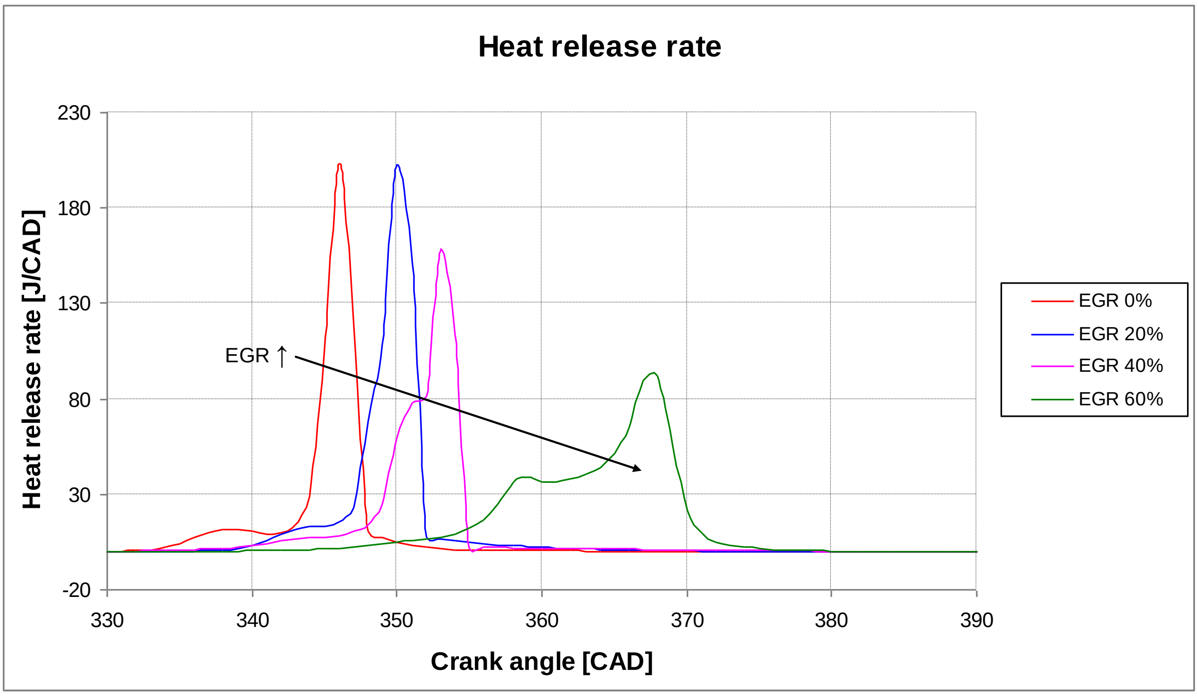

Figure 4. The influence of the EGR on the heat release rate

The mass fraction burned (MFB) for every engine cycle is a normalized quantity with a scale from 0 to 1 (0 before the combustion started, 1 after all the fuel was burned during the combustion). It is used to describe the chemical energy release process as a function of crank angle (4). It is calculated using the heat release rate diagram.

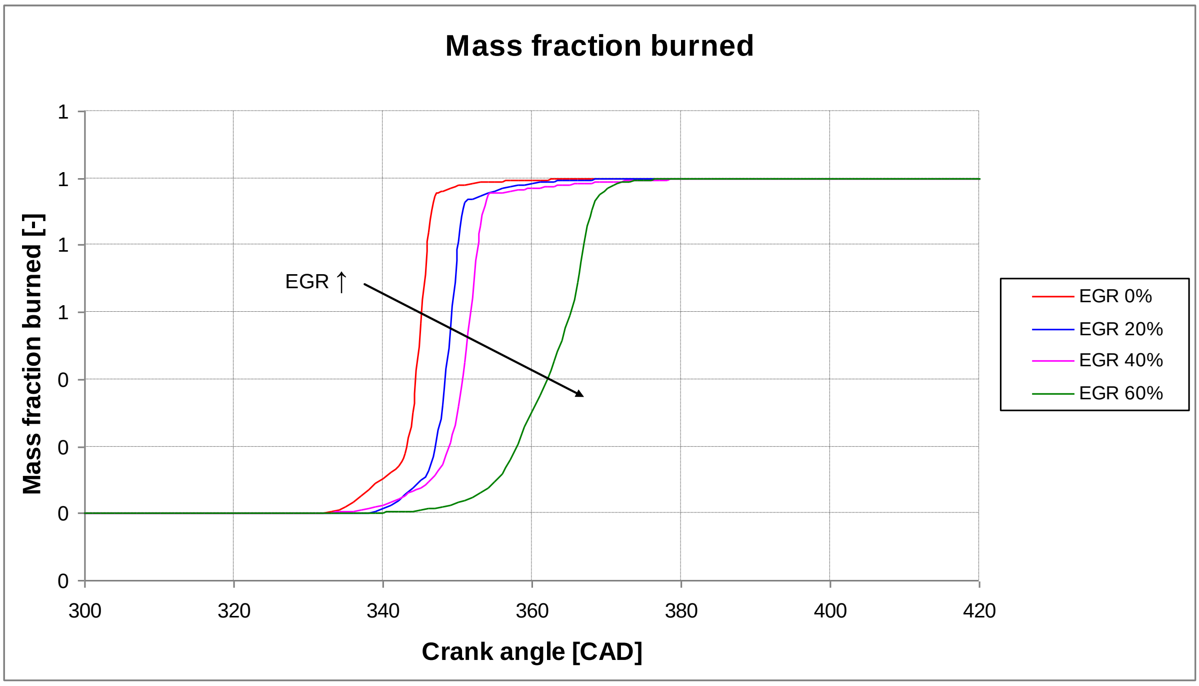

Figure 5. The influence of the EGR on the mass fraction burned

In figure 5 the evolution of the mass fraction burned can be observed. When the EGR is increased, the combustion is starting later and is longer.

CONCLUSIONS

The EGR is cooling the combustion, lowering the maximum pressures, maximum temperatures and delaying the moment when these values are obtained. The use of the EGR can lead to very low raw NOx emissions, but can increase the unburned hydrocarbon (HC) and carbon monoxide (CO) emissions.

The EGR is a method to extend the combustion duration, minimizing the maximum heat release rate and extending the engine operating range.

When higher EGR rates are used, the heat release rate peak corresponding to the low temperature oxidation can not be distinguished any more from the high temperature oxidation.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Baumgarten, C., “Mixture Formation in Internal Combustion Engine”, Springer, 2006
(2) Duret P., Gatellier B., Miche M., Montreiro L., Zima P., Marotaux D., Blundell D., Ganser M., Zhao H., Perozzi M., Araneo L., “Innovative Diesel HCCI Combustion”, EAEC European Automobile Engineers Cooperation Congress no. 9,p 57-68, 2003
(3) Heywood J.B. “Internal Combustion Engine Fundamentals”, McGraw-Hill, Inc., 1988
(4) Mendera K. Z., Spyra, A., Smereka, M., “Mass Fraction Burned Analysis”, Journal of KONES Internal Combustion Engines No. 3-4, p193-201, 2002
(5) Oakley A., Zhao H., Ladommatos N., Ma T., “Experimental Studies on Controlled Auto-Ignition (CAI) Combustion of Gasoline in a 4-Stroke Engine”, Society of Automotive Engineers, SAE paper no. 2001- 01-1030, 2001
(6) Onishi S., Jo S.H., Shoda K., Jo P.D., Kato S., “Active Thermo-Atmosphere Combustion (ATAC) – A New Combustion Process for Internal Combustion Engines”, Society of Automotive Engineers, SAE paper no. 790501, 1979
(7) Takeda Y., Keiichi N., Keiichi N., “Emission Characteristics of Premixed Lean Diesel Combustion with Extremely Early staged Fuel Injection”, Society of Automotive Engineers, SAE paper no. 961163, 1996
(8) Yanagihara H., “Ignition Timing Control at TOYOTA “UNIBUS” Combustion System”, Duret, A New Generation of Engine Combustion Processes for the Future, p 35–42, 2001