



INFLUENCE OF INJECTION PARAMETERS, OZONE SEEDING AND RESIDUAL NO ON A GCI ENGINE

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Introduction

Gasoline Compression Ignition (GCI) engines [1] based on Partially Premixed Combustion (PPC) have the potential to match Compression Ignition (CI) efficiency with reduced pollutant emission. Gasoline PPC has been shown to be effective at high load operating conditions [3–5], but low load operation still presents several challenges. Costly engine layout or the use of low octane gasoline still not available on the market, are necessary to overcome the low reactivity of gasoline at low load, discouraging automotive producers from adopting GCI. Another way to enhance the autoignition qualities of gasoline is to seed the intake of the engine with oxidizing chemical species. Previous studies [6–14] demonstrated that ozone strongly promotes premixed combustion of a large variety of fuels [7–9], and over a large range of engine operating conditions including nitrogen [11] and Exhaust Gas Recirculation (EGR) dilution [10]. Small concentrations of O₃ molecules seeding the intake manifold produced a strong acceleration in combustion phasing. Foucher et al. [6] demonstrated that the promoting effect of ozone is due to the alteration of the fuel oxidation chemical reaction-path. Kinetic modeling showed that during the compression stroke, O₃ molecules decompose, yielding O atoms, which hence substitute molecular oxygen in the initiation of fuel oxidation. In [9], experiments conducted on an engine fueled with iso-octane showed that ozone can also be employed to reduce the intake temperature required for fuel autoignition: 100 ppm of ozone were needed to reduce the intake temperature from 200°C to 120°C, while CA₅₀ was maintained at 0 CAD. The same results were also confirmed using CFD simulation based on the TDAC method [12]. In [11] ozone interaction with nitrogen oxides (NO, NO₂) was investigated showing that when NO and O₃ simultaneously seeded the intake of the engine, the impact of ozone could be reduced because of an interaction between the two molecules, depending on the NO+O₃→NO₂+O₂ reaction. The aim of the present work was to evaluate the potential of ozone to promote the autoignition reactivity of a high-octane commercial gasoline, when fuel was direct-injected in a CI engine running at low load. Since the impact of ozone on a DI engine has never been studied, experiments in a single cylinder Diesel engine and results from autoignition

computations based on a detailed kinetic mechanism were employed to give an interpretation of the impact of ozone over GCI conditions.

Experimental Setup and Kinetic Simulation.

Experiments were carried out in a Peugeot DW10-series Diesel engine converted for single cylinder operation and maintained at a constant rotation speed of 1500 rpm. The displacement is 0.5 L/cylinder and the compression ratio (CR) is 16. A high pressure pump, connected to a Diesel common rail system, supplied a 400 bar injection pressure. Two different Delphi Diesel injectors, with a wide (154°) and a narrow (90°) umbrella angle were chosen for the direct injection of commercial RON95 gasoline. A global fuel-air equivalence ratio of 0.3 was fixed for all the experiments. Intake pressure was set a 1 bar and the intake air temperature at 187°C. The ozone was produced by a corona-discharge ozone generator and then injected into a plenum positioned upstream of the intake manifold. The kinetic analyses conducted in this investigation were performed using the Senkin package and a detailed kinetic scheme of iso-octane oxidation developed and validated by Curran et al. [15] and two sub-mechanisms: one for ozone and one for nitrogen oxides (NO and NO₂).

Ozone Decomposition

At the heart of using ozone to promote the autoignition of direct injected Gasoline is the ozone life-cycle. In fact, because of in-cylinder pressure and temperature, ozone decomposes after seeding the intake of the engine, in accordance with the reactions $O_3 + N_2 \rightarrow O_2 + O + N_2$, $O_3 + O_2 \rightarrow O_2 + O + O_2$ and $O_3 + M \rightarrow O + O_2$, leading to O free radicals responsible for combustion enhancement. The decomposition of ozone was studied through kinetic modelling. Figure 1 shows the in-cylinder concentration of free radicals of oxygen coming from O₃ decomposition. Calculation showed that the availability of free radicals presents a maximum some crank angle degrees before top dead center, then decreases because highly reactive O atoms recombine, yielding O₂ molecules. The O evolution suggests that in

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order to optimize the ozone improvement of combustion, the injection timing should be sufficiently advanced to match with the maximum availability of O atoms.

Impact of Ozone as a function of Injection Timing

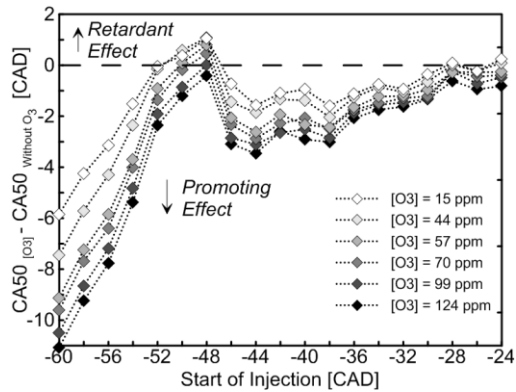


Figure 1 - Shift of the CA50 as a function of SOI for different O₃ concentrations.

An investigation into low load operating conditions of a Direct-Injection GCI engine fueled with RON95 gasoline was performed at a constant fueling rate leading to a global fuel to air equivalence ratio of 0.3. The first part of this study focused on choosing the best injector system to obtain the ozone effect. A Diesel injector with 156° umbrella angle was not suitable to observe the effect of ozone because of the limited SOI range. Using an injector with a 90° narrower umbrella angle extended the SOI range up to -60 CAD enabling the promoting effect of ozone. Moreover, the injector with a 90° umbrella angle showed better performance in terms of indicated efficiency, combustion efficiency, and pollutant emission of HC if compared to a 156° Diesel injector. Autoignition of gasoline was then analyzed as a function of the start of injection, and results showed that at early injection timing, combustion is strongly influenced by the NO trapped into the residual burnt gases. At later injection timing, local distribution of the temperature and the equivalence ratio mainly drive the onset of combustion. The ozone effect was then investigated using the 90° umbrella angle injector over a wide range of injection timing, as showed in Figure 1. Stronger impacts of ozone, comparable to those observed in HCCI conditions, were observed at early injection timing. If the operating range is characterized by higher NO_x emissions (i.e. in the SOI range between SOI = -54 CAD and SOI = -48 CAD), the residual NO trapped between subsequent cycles can react with O₃ molecules drastically reducing or even making the promoting effect of ozone ineffective. Later injection timings are less suitable to capitalize on the ozone effect because of ozone decomposition and because local tem-

perature and equivalence ratio distribution have a stronger impact on the onset of combustion.

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