Rate of injection modelling for gasoline direct injectors

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ABSTRACT

Awareness of climate change, fossil fuel availability, and pollutants has been growing which have pushed forward the effort in cleaner engines. In this aspect, the gasoline engines have more improving margin than diesel engines. To have a more efficient combustion, injection systems had evolved from old Port Fuel Injectors to modern Gasoline direct injections which are the used by engine manufacturers nowadays. In this study, within the framework of the Engine Combustion Network (ECN), the so named Spray G is modelled. This gasoline direct injector was developed by Delphi with the intention of getting a better understanding of the gasoline spray. The model is focused on the Rate of Injection (ROI) signal, whose results are presented in order to help engine calibration and modelling for an extensive range of configurations without the need for experimental measurements.

1. Introduction

Internal combustion engines have shaped the modern world socially and economically. Since the first patented automobile, the auto market has been growing steadily to become one of the biggest industries today. However, the increasing amount of engines has led to concerns about emissions. Regulations arose in order to control those, thus to be in the market engine manufacturers had to meet emission targets through engine optimization [1–3]. A good fuel-air mixture could improve combustion and efficiency which led reduced pollutants. This is mainly achieved by the fuel injection system and the injection strategy. Early injection systems for gasoline include carburetor, which provides little control on the injection. Later, Port Fuel Injection (PFI) technology led to better control in the demand of fuel [4]. At that point gasoline engines usually have been cleaner by means of toxic emissions and pollutants than diesel engines because of the combustion of a homogeneous mixture at relatively low temperature. However, the latter advantage is diminished when looking at fuel economy and CO2 emissions. The research path to improve the performance went into new strategies that required better control of the fuel injected [5] as well as the use of common rail injection system [6]. The Gasoline Direct Injection (GDi) technology in gasoline engine was pursued to perform more refined injection strategies which have the potential to increase performance, fuel economy and performance of gasoline engines [7,8]. For instance, some challenging scenarios that the GDi technology could improve are engine acceleration and in cold starts. Although some predictions state that GDi systems are expected to overtake PFI systems by 2020, for the moment GDi engines have several essential drawbacks such as emissions, complexity, cost, etc., that prevent them from being widely accepted [4,9].

The advancements in engine performance can be done using different analysis techniques. Combustion diagnosis models in gasoline are based in [10,11], which measure the instantaneous pressure in the cylinder and determine the rate of heat release (RoHR). Other studies analyze the reactive spray properties such as Payri et al. [12]. Combustion diagnosis are necessary for better control equations of the thermal process in the engine [13]. Conversely, Computational Fluid Dynamic (CFD) together with engine testing allows to obtain information of the flow field and permit to estimate the trends of the emissions to act accordingly, by means of 0D, 1D and 2-3D simulations [14–16]. For the diagnostics, it has to be noted that an important input parameter is the injected mass into the system and the shape of the injection event.

The measure of Rate of injection (ROI) [17], is achieved from experimental sources, with controlled and stabilized boundary conditions. These measurements are of vital importance to validate CFD models, which can provide detailed information of the injection/combustion process as seen in [17–19]. In the case of flash boiling conditions for GDi, it is crucial to validating works such as [20,21]. Nonetheless, the number of test points that have to be measured to achieve all the desired engine conditions could be exceptionally large. Other option to get all the desired conditions is through a model of the shape of the injection rate. This will reduce the experimental matrix and supplement with all conditions that haven't been measured, providing a full database of the ROI signal.

There have been studies in the modelling of the injection system for diesel engines by modelling the dynamic behaviour [22–24]. The 1D modelling includes all the components such as pump, injector and valves, which requires to have detailed information to understand all the process geometries and physical phenomena behind. Conversely, the 0D model is understood as a black box whose outputs are obtained by mathematical expressions without considering detailed knowledge of the systems. Little work has been done using this approach, however, Payri et al. [25] presented a detailed methodology to follow where a Diesel injector was modelled, including multi-injection events. In the case of Gasoline injectors there has not been done to the best knowledge of the authors.

In this work, the 0D ROI model of a Delphi gasoline direct injector was performed. The results will be available in order to provide a tool to the Engine Combustion Network research group and other researchers working with GDi injectors. After this model is presented, an extension of the methodology is done for a Bosch GDi injector.

2. Experimental tools and hardware

2.1. Gdi injector

As previously mentioned, the injector used in this work is the Spray G injector which was intentionally made for research activities of the ECN group, within the Spray G topic. The nominal conditions of the spray G are depicted in Table 1.

To facilitate the CFD, a gasoline surrogate has been employed. The fuel chosen to imitate the gasoline has been iso-octane (2,2,4 tri-methylpentane) for being a mono-component fuel close to gasoline in specifications as seen in [26,27]. It has a density of 692 kg/m^3 (at STP) and a kinematic viscosity of 4.8×10^{-4} Pa s (at 25 °C). The injector and driver (ECU) have been manufactured by Delphi, following the specifications of the group (see Table 2).

2.2. Injection systems and test conditions

A complete common rail injection system was used to generate high pressure in the test rig used in this work, similarly to the one used in [28,26]. The system is composed of the Delphi ECN spray G injector, a trigger generator which commands the signal to the Engine Central Unit

Table 1
ECN Spray G conditions.

Parameter	Value	Units
Fuel	Iso-Octane	–
Fuel pressure (P_{inj})	20	MPa
Fuel temperature	90	°C
Injector temperature	90	°C
Chamber pressure	6	bar
Chamber temperature	300	°C

Table 2
ECN injector specifications.

Parameter	Value	Units
Number of holes	8	–
Inner diameter	165	(μm)
Outlet diameter	388	(μm)
Spray shape	Circular	
Spray angle	80	°
Bend angle	0	°
L/D ratio	2	–
Hole shape	Straight	–
Manufacturing	EDM	–
Flow rate	15(cc/s) @ 10 MPa	

Table 3
Test matrix for measurements of Spray G injector.

Parameter	Tested values	Units
Rail pressure (Pr)	50/80/100/120/150/180/200	bar
Back pressure (Pb)	3/6/9/15/21	bar
Energizing time	280/300/350/680/900/1200	μs
Cycles for test condition	50	–

(ECU), a rail, thermo-regulator and a high pressure pump. The high pressure pump was originally acquired to provide pressure to diesel injectors. Thus, a frequency regulator was located in the pump to achieve better control under relative low injection pressure compared to diesel however common for GDi injectors. This allows operating with pressure as low as 8 MPa and up to 23 MPa at a relatively constant value. The thermo-regulator permitted to set an injector holder temperature of 90 °C for all experimental test conditions using glycol as cooling fluid. The back pressure was achieved providing the cavity in the test rig with nitrogen gas, and it was varied from 1 to 10 bar. The duration of the energizing time (ET) was varied between a short pulse of 220 μs, which is representative of pilot injections, and a long pulse of 1200 μs which is sufficient to guarantee that the needle position is at maximum lift, so the flow is controlled by the nozzle geometry. The experiments were performed in a systematic manner, changing the ET, Injection pressure and back pressure. The measurements were done once enough time passed at each condition and the values were stabilized. The executed experimental matrix is summarized in Table 3. The Reynolds number range for the injection conditions used at the nozzle exit was from 3×10^4 to 7×10^4.

2.3. Rate of injection test rig

The mass ejected was measured using a ROI test rig, being a long-tubed type commercial equipment. The sensor in the device can measure the time-resolved injection event. The measuring principle used is