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Injection Systems in Diesel Engines and Their Theoretical-Experimental Study: A Review

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Abstract

The injection systems have had a strong evolution in recent years, going from low-pressure system of a mechanical drive to complex high-pressure electronic systems. The electronics applied to this type of systems has allowed handling sequential injections and increasing the injection pressure. In the present work a review of the evolution of the injection systems in the last 20 years is made and how techniques have been developed to model the hydrodynamic behavior of the injectors in Diesel internal combustion engines. With this review, the trends for the modeling of the injection process are visualized, which has an important impact on the thermodynamic modeling and the prediction of the indicator parameters in Diesel internal combustion engines. This review allows to visualize the future development of this type of systems and the implications they have on the performance of internal combustion engines and the thermodynamic modeling of them. The optimization in the operation of diesel engines is possible by improving the operation of injection systems, which has led to more powerful engines but smaller.

Keywords: Diesel, Evolution, Engines, Emissions, Injection Systems

1. Introduction

Internal combustion engines are the most common devices to transform the energy released from a chemical process from a fuel into mechanical energy. Since the mid-nineteenth century to the present day, internal combustion engines have operated under the same operating principle, which consists of four stages that are: intake, compression, expansion, and exhaust; and they can be classified according to the ignition type in Otto cycle and Diesel cycle engines [1] [2].
Although the principle of operation has been maintained, the effort on the part of engineers is focused on optimizing the efficiency of internal combustion engines and reducing fuel consumption. With the increase in the demand of Diesel engines and with the importance that has taken care of the environment due to increasingly stringent regulations such as the EURO 6, technologies have been developed that allows a reduction of the polluting emissions, as well as configurations for improving combustion [3]. To carry out this purpose, different techniques have been proposed, including reducing the combustion temperature to reduce the formation of Nitrogen Oxides [4], recirculation of exhaust gases EGR [5], emulsion [6], injection as the common rail where high pressures (above 1500 bar) are handled [7] [8], multiple injections [9], geometry of the nozzle [10], among others.
Diesel engines are characterized by the use of a direct injection system, which indicates that the fuel is injected into the combustion chamber. Furthermore, during the compression cycle, the air is compressed and when the top dead center is reached, the liquid fuel is injected, which is then evaporated to mix with the air, taking into account different parameters such as the injection pressure, the diameter of the nozzle , the angle of opening of the jet (which depends on the geometry of the nozzle and the density of the gas in the chamber) and the time that elapses between the start of the injection and the end of the injection, which will influence the rate of fuel injected and in the proportions resulting from the exhaust gases [3].
During the combustion process in Diesel engines, the liquid fuel injected or also known as Diesel jet has incidence on the flame and the formation of the exhaust gases and it is fundamental to understand its development as the model presented by Dec [11], which describes the stages that the Diesel jet experiences from the start of the injection until its progress in a stationary jet. It should be noted that in the Diesel jet there are important distances such as liquid length, lift-off length, flame length and free jet length [12]. In addition to the different parameters that affect the combustion process and the percentage of formation of the exhaust gases, it is important to understand how the injected fuel rate and the discharge coefficient influence these processes.

2. Advances and investigations in injection systems

2.1. Evolution of injection systems

The first injection system developed was the online injection system, this type of pump designed by Robert Bosch in the early twentieth century had been the most

used, not to say the only one that worked especially in heavy vehicles, but it was replaced by smaller rotary pumps that were more suitable for fast motors. This type of pumps has a very robust constitution and proven mechanical reliability, due to its size, weight, and limitations that are limited to some revolutions that make them suitable for heavy vehicles, but not for passenger cars.
The injection system by linear pump had two main drawbacks, first its large size and second a high cost due to the requirement of a pump for each cylinder, to solve these defects was designed the rotary pump injection system that is much more compact and It is also lubricated by the same fuel that it pumps, so it can work in any position.
One of the problems that manage the aforementioned systems is the constant variation of pressure in its parts, which leads to wear of its elements, so systems have been devised where a high-pressure pump is responsible for raising the pressure constantly within a system of common pipes, the most used system that follows this principle is the common rail system, in this system the one in charge of compressing the fuel is the high-pressure pump and the one in charge of dosing the fuel and atomizing it are the injectors, this system of injection reduces the sound produced by the engine and emissions emitted [12].

2.2.Theoretical-experimental study of injection

Liu et al. [13], showed in their study how the low temperatures affect the combustion of the Diesel jet increasing the lift-off length and the delay time, together with low temperatures, the injection pressure has little significance over the length of the Lift-off and delay time. As the temperature affects the lift-off length, the geometry of the nozzle is another important parameter to be considered as demonstrated by Payri et al. [14], which considered three fuels and two nozzles with different geometries; one consisted of a conical shape, while the other had a circular hole, but with a diameter 8.6% larger than the conical one. The results obtained experimentally indicated that the conical geometry has a longer lift-off length when compared to circular geometry, and a shorter delay time, highlighting that it may be due to the liquid length evaporating faster than in the circular nozzle.
Desantes et al [15], in their study generated a system that allows to modify the pilot injection and turn the instantaneous rate of injection, considering the speed of rotation of the engine and the mass of fuel, in their results detailed that the speed influenced little in the combustion process, in terms of pilot injection there were NOx reduction and an increase in soot and fuel consumption. Also, they specified that at a slow injection rate two opposite effects could occur, on the one hand, there is a lower mass of fuel injected and on the other, due to low pressure, the delay time is extended causing a later ignition causing Accumulate the mass of fuel before combustion. On the other hand, Tang et al. [16], determined that the diameter of the orifice of the nozzle represents an important parameter and at lower diameters, there is a significant increase in the injection rate.
In more recent studies Ferrari and Paolicelli [17], proposed a numerical model that allows converting pressure data in instantaneous injection rate; in turn integrating

the calculated rate, you get the amount of fuel that enters the injector. With the numerical model, the amount of fuel that enters the injector is greater than the injected measured by a flowmeter, in addition the two masses follow the same trend with respect to parameters such as pressure and time of energized; which allowed them to find a correlation limited to a mass of injected fuel less than 4 mg [18]-[20].

3. Discussion

Below It has started from different approaches to model the injection process in diesel engines, with different objectives, there are some studies that opt for the spray moment flow analysis method, others opt for the analysis of equations already established as eulerian- lagrangian or Navier-stokes, some are more pragmatic and opt for optical analysis such as x-rays, on the other hand there are those who choose an approach from chemical kinetics, a few propose novel approaches such as the large swirl simulation volume method multiphase, but the vast majority is opting for computational flow analysis (CFD) with programs such as ANSYS and AVL BOOST.

An example of the first-mentioned approach is the work of Luo [21], in which they make a modeling of each 1 of the orifices of a multi-orifice injector or Long Liu's work [22], which develops a model for the simple and analytical diesel pulverization, which includes the evolution of the spray after the end of the injection.

On the other hand there are works that follow the second approach as the work of Amin Yousefi [23] that models different types of injection for heavy services at low loads or that of Madjid Birouk [24] that analyzes the effect of the injection delay on the Emissions, both choose to follow the system of Navier-stokes equations, others like Pang Kar [25] choose to follow a Eurelian stochastic method to know how the ignition flame develops.

In the case of the third approach we have works such as Rao [26], which measures the effect of post-injections on emissions in small diesel engines with optical exams to experimental designs or the work of Seoksu Moon [27] who opts for the use of x-rays to discover how the injector needle affects the flow through each orifice of the injector in single hole, 3-hole, and 6-hole injectors.

In the fourth approach we find works such as Poorghasemi [28], which achieves a model that simulates 3D combustion and predicts emissions for direct injection (DI) and the controlled compression ignition method (RCCI) or Dezhi work Zhou [29] that studies the effect of injection timing on the start injection rate on emissions and combustion characteristics in a direct injection compression engine (DICI).

Yu [30] that follows a multiphase model large eddy simulation-volume of fluid (LES-VOF) or the work of Fuying Xue [31] that opts for a homogeneous flow approach and fluid volume method to analyze the flow in each orifice in an asymmetric injection nozzle using a liquid-gas phase flow model.

But the trend is clear to opt for CFD analysis, in this group we have worked like those of Marčič [32] who model the liquid jet phase using CFD and effects of eccentric movements [33]. On the other hand, Eloisa Torres-Jimenez [34] proposes the development of a simulation model for diesel, biodiesel and bioethanol injection systems with the AVL BOOST program, including works such as those of A.Pandal [35] that creates a solver from a Eulerian atomization model coupled to the combustion model ADF in the OpenFOAM platform.

4. Conclusions

It is clear that systems that use a CFD approach give better results with a lower investment at the time of experimentation so it is a very attractive approach, by dividing the fluid into nodes you can make a general and very detailed analysis of the injection in General and can be predicted from the size of the drop to the level of diesel-air mixture, both essential factors if you want to affect the emissions or the thermal performance of the engine. The evolution of the injection systems has allowed a noticeable improvement in the performance of internal combustion engines and their emissions. Therefore, there have been great advances in the theoretical and experimental analysis. However, a predictive model that fully describes the physical processes that occur in injection systems has not yet been developed. Most of the cited correlations, although simple to apply, require detailed information which is difficult to measure and is not available at the design stage.
Given the above, and the importance of this phenomenon, it is necessary to develop more robust predictive models that characterize the injection process under transitory conditions. Similarly, the use of CFD tools potentiates the study of this type of systems, so that a contribution was made to the thermodynamic modeling of Diesel internal combustion engines.

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