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Experimental analysis of a diesel engine operating in Diesel–Ethanol Dual-Fuel mode

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HIGHLIGHTS

- We used a single cylinder engine, in the Dual-Fuel mode, to obtain experimental data.
- It was used a direct injection system for the diesel fuel.
- It was used a port ethanol injection 100% electronically controlled.
- Compression ratios were adjusted at 3 different levels: 14:1, 16:1 and 17:1.
- The highest substitution rates occurred at CR of 16:1, reaching more than 50%.

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ABSTRACT

The use of engines is necessary to keep the world moving. Such engines are fed mainly by fossil fuels, among these, the diesel. The operation and the behavior of engines in different thermodynamic cycles, with common fossil fuels, it is still challenging but, in general, it has well known and documented data. On the other hand, for alternative fuels, there is still demand of experimental data, particularly considering that it is desirable, most of the times, the use of a system with dual mode (reversible). Such systems are called Dual-Fuel, it brings a greater degree of freedom, but imply in technological challenges. In this paper we used an engine operating with single cylinder direct injection diesel and port ethanol injection system in Dual-Fuel mode with a 100% electronically controlled calibration. The methodology applied was, once the engine calibration was given to achieve the best specific fuel consumption or the MBT (Maximum Brake Torque) in each load condition, to gradually substitute the diesel oil by ethanol in compliance with the requirements established. Comparisons were made among working conditions considering the rate of diesel substitution and the energy indicated efficiency. Initially, the flow structure in the combustion chamber was tested in both 'quiescent' and high "swirl" modes. Compression ratios were adjusted at 3 different levels: 14:1, 16:1 and 17:1. It was tested two injectors, the first one of 35 g/s and another of 45 g/s. Regarding pressure diesel injection, 4 levels were investigated namely 800, 1000, 1200 and 1400 bar.

1. Introduction

Q4 The development of the current society has been, until now, largely associated to the use of fossil fuels. It can be confirmed with Q5 data from 2010 (Hoeven, 2010) that indicate that 43% of CO_2 emissions from fuel combustion were produced from coal, 36% from oil and 20% from gas. One strategic way to reduce the damage of this dependence is through the use of alternative fuels, among these, the ethanol. Ethanol is an attractive alternative fuel because it is a biological resource base and it is oxygenated, thereby providing the potential to reduce particulate emissions in compression ignition engines. It is accepted that the addition of ethanol to diesel oil have the beneficial effect of reducing emissions of particulates. Boretti [3] notes that among the biggest advantages of using the Dual-Fuel mode with Diesel–Ethanol are the CO_2 emissions reduction, following the fuel life cycle analysis; a possible reduction of both smoke and particulate matter emissions; a better sustainability of the renewable fuel and finally, better energy security. In fact, the replacement of the fossil fuels consumption by ethanol could significantly reduce CO_2 emissions based on WTW analysis

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Nomenclature

AFR	air fuel ratio
AI50	crank angle of 50% mass fraction burned
AI50-D	crank angle of 50% mass fraction burned with diesel only (baseline)
BNDES	Banco National de Desenvolvimento Econômico e Social
CI	compression ignition
CNG	Compressed Natural Gas
CR	compression ratio
SAE	Society of Automotive Engineers
MBT	Maximum Brake Torque
IMEP	indicated mean effective pressure
°CA	Crank Angle Degree
COV_{IMEP}	IMEP coefficient of variation
DFMI	Dual-Fuel Mixed Ignition
EGR	Exhaust Gas Recirculation
RMax	Maximum Rate of Rise of Combustion Pressure
RON	Research Octane Number
COV-DE	COV of IMEP in Diesel–Ethanol mode
COV-D	COV of IMEP with diesel only (baseline)
Ind.Eff.-DE	indicated Efficiency in Diesel–Ethanol mode
Ind.Eff.-D	indicated efficiency with diesel only (baseline)
Lambda-DE	air excess coefficient in Diesel–Ethanol mode
Lambda-D	air excess coefficient with diesel only (baseline)
LHV	Lower Heating Value
m	mass
Nd:YAG	Neodymium-doped Yttrium Aluminum Garnet
PFI	Port Fuel Injection
Ottolization	diesel to Otto cycle conversion
SOI	Start Of Injection
VSE	Vale Soluções em Energia
WTW	Well-to-Wheel

(Well-to-Wheels, 2007), especially if the biofuel is produced from sugar cane as it is the case in Brazil, or the diesel used nowadays in the ethanol production process chain (production inputs transportation, preparation for sugar cane planting and transportation, etc.) was replaced by biofuel.

An important aspect of any substitution regards to safety aspects. Waterland et al. [17] published the safety aspects and performance analysis of ethanol blends in engines which run originally with diesel only, but without setting the start point of injection to optimize the overall efficiency of the engine to the new fuel. Another aspect to consider is the chemical properties of the ethanol when compared to diesel. Authors as Satgé de Caro et al. [14] and Hansen et al. (2007) discuss the properties and specifications of ethanol blended with diesel fuel, such as stability, viscosity, lubricity, safety and materials compatibility. They considered the effect of the fuel on the engine performance, durability and emissions. Finally, they suggested the formulation of additives to correct certain key properties and maintain blend stability, since a critical factor is to ensure compatibility between the fuel and the engine. To date, no engine manufacturer indicated that they will extend the warranty coverage of their equipment if they are operating with E-diesel (Diesel–Ethanol blend). They believe that there are still many unanswered questions, as well as the potential of passive exposure due to an increased flammable range of E-diesel, as mentioned by Nylund et al. [12]. Therefore, the critical factors of the potential commercial use of these mixtures include properties such as viscosity, stability and lubricity, safety and material compatibility plus their performance characteristics and emissions. These matters, although very important, will not be covered in the present work for the Dual-Fuel concept.

The motivation for this work is related to the growing interest in biofuels for transportation and industrial applications. Taking into account the environmental aspects, the ethanol in Dual Fuel system may be a feasible alternative for the usage of biofuel in some applications, since changes in Diesel base engines internal components is probably not mandatory. However, at least it is required the development of a PFI (Port Fuel Injection) system to operate the engine in this condition. The PFI system has already been demonstrated to be technically feasible for a 6 cylinder engine of 11.7 l displacement which was originally Diesel and then 'Ottolized' to operate at 100% hydrated ethanol according to Britto et al. [4]. In the present work it was tested different Diesel–Ethanol proportions at different engine operating conditions and the base for the comparison is the results obtained using pure diesel.

2. Global context of the Diesel–Ethanol in the Dual-Fuel mode

Different 'Dual Fuel' systems, which include diesel, have been built and used in varied applications. The Dual-Fuel engine is based on a traditional Diesel engine, with the addition of a specific hardware applied to Dual-Fuel.

There are several systems report to Diesel–CNG, among them, studies related by Wannatong et al. [16], Maji et al. [10], Yoshimoto [20] and Wierzbicki [19]. Pawlak [13], for example, tested one 2.6-l, four cylinder compression ignition engine, with 17.5:1 of compression ratio (CR), adapted to a Dual-Fuel with direct injection of diesel oil and port injection of natural gas. He mentioned about up to 80% of diesel substitution in energy basis at 75% of full load. At higher loads, around of 11 MPa of maximum cylinder pressure, the substitution level was between 45% and 50%. To achieve these results and maximum engine overall efficiency, the injection timing was optimized for each torque and engine speed. There are also companies which already have solutions that include products with Diesel–CNG, for example, Clean Air Power [5] and Westport [18], who developed fuel injection systems and their components. There are also Dual-Fuel systems running with Diesel–Gasoline [9]. Leermakers et al. [9] performed an investigation with a test cylinder (130 mm of bore, 158 mm of stroke and 15:1 of compression ratio), geometrically similar to that one used in the present work, (see Table 1), running in the Dual-Fuel mode. This test cylinder was equipped with a port gasoline injection (RON 95) complementing the stand-alone diesel injection system, EGR (Exhaust Gas Recirculation) circuit, and air compressor. Timing and rate of heat release can be directly controlled by varying the balance

Table 1
Test engine technical characteristics.

Description	Value	Unit
Engine specification		
Displacement	2.06	l
Stroke	160	mm
Bore	128	mm
Number of cylinders	1	
Compression ratio	13:1 to 19:1	
Number of inlet valves per cylinder	2	
Number of exhaust valves per cylinder	2	
Diesel injection type	Direct	
Ethanol injection type	PFI	
Piston geometry	"Mexican Hat"	