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Emission analysis of a Diesel Engine Operating in Diesel–Ethanol Dual-Fuel mode

Roberto Freitas Britto Júnior [a,b], Cristiane Aparecida Martins [a,*]

[a] Departamento de Propulsão, Instituto Tecnológico de Aeronáutica, 12228-210 São José dos Campos, SP, Brazil
[b] Vale Soluções em Energia, São José dos Campos, SP, Brazil

HIGHLIGHTS

- Diesel engine.
- Ethanol fuel.
- Dual mode.
- Experimental tests.
- Gas emissions.

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ABSTRACT

Among the motivating factors for studies involving thermal machines is the need to increase the range of options. Thus, various systems combinations can co-exist, causing the reduced reliance on a single source. This is the context of studies involving Dual-Fuel systems. Additional to this factor is the requirement to reduce emissions. Thus, the combination of fuel, one being an alternative fuel becomes a very convenient opportunity. In this work, emissions results of a Diesel–Ethanol Dual-Fuel system are presented. A single cylinder research engine with diesel direct injection and port ethanol injection that aim to form a homogeneous air–fuel mixture in the intake port was used. The initial idea was to achieve the highest possible diesel substitution rate by ethanol. After investigation, described in a previous study with different compression ratios, different flow structures, different diesel injectors' flows and injection pressures it was found that the highest substitution rate occurred with higher injector flow, compression ratio of 17:1, high swirl flow structure. The present work will discuss the emissions results obtained in that engine configuration which was considered optimal balance between diesel substitution rate and efficiency. Diesel Engine Operating in Diesel–Ethanol Dual-Fuel mode reduced the NOx emission in up to 60%. On the other hand, there was increase of the THC, the CO and the aldehydes, showing a trade-off that must be further investigated with a final design engine, in the beginning of product development process.

1. Introduction

Studies involving ethanol in the Brazil are very convenient, considering the infrastructure and its availability. Nonetheless, today the majority of heavy duty engines available in the Brazilian market, considering both stationary and vehicular engines applications, are still fueled with diesel only. On the other hand, here and in other parts of the world there are studies whose main objective is to substitute the diesel usage with ethanol. Among the technical solutions which involve hardware design changes and conversion of original Diesel engines, are the following:

1. Use of 100% ethanol with compression ignition by mean of its additivation, increase of both compression ratio and injection flow mass.
2. Mixture of diesel–ethanol using suitable additives.
3. Use of 100% hydrated ethanol with spark ignition. In this case CR reduction is used, replacement of the diesel injector by spark plug and implementation of a PFI (Port Fuel Injection) system, Britto et al. [11].
4. Partial substitution of diesel by ethanol through the compression ignition of a diesel pilot injection and addition of a PFI system for ethanol injection in the intake air [10].

* Corresponding author at: ITA/IAE – Departamento de Propulsão, Praça Marechal Eduardo Gomes, 50, CEP 12228-900, São José dos Campos, SP, Brazil. Tel.: +55 12 39475826.

E-mail address: cmartins@ita.br (C.A. Martins).

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Nomenclature

AFR	Air Fuel Ratio
AI50	50% of mass fraction burned
ANP	Agência Nacional do Petróleo
CNG	compressed natural gas
CR	compression ratio
EPA	environmental protection agency
SAE	Society of Automotive Engineers
M	molecular mass of the gas
MBT	Maximum Brake Torque
IMEP	Indicated Mean Effective Pressure
°CA	crankshaft angle degree
COV_{IMEP}	IMEP coefficient of variation
DE	Diesel–Ethanol
E_g	engine pollutant specific emission
EGR	exhaust gas recirculation
FTIR	Fourier Transform Infrared
$[g]$	gas volumetric concentration
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)
IMEP	Indicated Mean Effective Pressure
Lambda-DE	air excess coefficient in Diesel–Ethanol mode
Lambda-D	air excess coefficient with diesel only (baseline)
LHV	Lower Heat Value
M_d	exhaust molar mass per mole of burned diesel
M_e	exhaust molar mass per mole of burned ethanol
M_E	total molecular mass of the exhaust gases
m_g	gas mass
m_E	exhaust total mass
$\dot{m}_E$	total exhaust mass flow rate
$\dot{m}_e$	ethanol mass flow consumption
$\dot{m}_d$	diesel mass flow consumption
MBT	Maximum Brake Torque
n	amount of gas measured in moles
Nd:YAG	neodymium-doped yttrium aluminum garnet
NO	nitric oxide
NO_2	nitrogen dioxide
P	pressure of gas
P_i	indicated power
PFI	Port Fuel Injection
PM	Particulate Matter
Ottolization	diesel to otto cycle conversion
R	universal gas constant
RME	Rape Methyl Ester
SCRE	single cylinder research engine
SI	spark ignition
SOI	start of injection
T_1	mixture temperature at the start of compression
T_2	temperature at the end of compression
Teq	reaction equilibrium temperature
THC	total hydrocarbons
V	volume of gas
V_E	total exhaust gases volume
V_g	gas volume
VSE	Vale Soluções em Energia
w_g	gas mass fraction
WTW	well-to-wheel
ω_{NO}	NO formation rate
x_S	sulfur mole fraction
x_w	sulfur mole fraction
λ	air excess coefficient
ρ_E	total exhaust gases density
ρ_g	gas density

In short, studies which include ethanol and diesel, involve the utilization of different techniques as well as ∗∗the ones described by Abu-Qudais et al. [2]. Often these studies are focused on performance, although there are some whose concerns are performance and engine emissions (Hansen et al. [23]). It is accepted that the diesel–ethanol blend is able to, at least reduce the PM (Particulate Matter) [22].

Some studies apply the use of ethanol in the Dual-Fuel mode, but using RME (Rape Methyl Ester) as the main fuel instead of standard diesel, Kowalewicz [28]. In this study performance results and emissions was presented. A single cylinder engine of 980 cm^3 displacement was utilized which was tested with only 3 different values of SOI (Start of injection) for all operational conditions. Egúsquiza et al. [19] also tested a single cylinder engine, with 1075 cm^3 of displacement, running in Dual-Fuel mode, either Diesel–Ethanol or Diesel-CNG. Padala et al. [33] used a smaller cylinder (497.8 cm^3) in Dual-Fuel mode using standard diesel for the pilot injection and ethanol as secondary fuel. These earlier studies had involved the use of small sized cylinder. Due to this, they probably have less limitation for engine calibration once they have a lower knocking tendency [25].

In the present study, an engine with larger cylinder bore diameter was used, compared with other studies, although its knocking trend is higher. Larger cylinder bores are used in heavy duty application, which means the used engine is closer to practical reality, making this factor a great advantage for this work.

The dynamometer testing and calibration of engine fuel injection systems was conducted to maximize energetic substitution ratio of diesel by ethanol. Fig. 1 shows the different values achieved by various authors and technologies, at different running condition, considering only the maximum diesel substitution in terms of energy.

2. Experiment description

This work is based on dynamometer tests using a single cylinder research engine (SCRE) running on Dual-Fuel mode with diesel and hydrated ethanol at ANP (Agência Nacional do Petróleo) standard.

The engine used in these tests, a single cylinder research engine with 2.06 l of displacement, has 128 mm of cylinder bore, typical cylinder head and combustion chamber design from Diesel engines with two intake and two exhaust valves. The engine compression ratio can be adjusted from 13:1 up to 19:1. The diesel injector is located in the center of the combustion chamber and two ethanol injectors with typical PFI specification, one per intake runner, are positioned upstream of the cylinder head inlet. Fig. 2 illustrates parts that involve the cylinder head and intake system.

3. Methodology

In this engine, in an earlier study [10], three different compression ratios (14:1, 16:1 and 17:1), two diesel injectors, one with 35 g/s and other with 45 g/s of static flow, and four diesel injection pressures (800, 1000, 1200 and 1400 bar) were investigated. The control variables of engine calibration were the diesel SOI (Start of Injection) and energetic substitution rate of diesel by ethanol.