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Towards improvement of natural gas-diesel dual fuel mode: An experimental investigation on performance and exhaust emissions

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ABSTRACT

The use of natural gas in compression ignition engines as supplement to liquid diesel in a dual fuel combustion mode is a promising technique. In this study, the effect of DF (dual fuel) operating mode on combustion characteristics, engine performances and pollutants emissions of an existing diesel engine using natural gas as primary fuel and neat diesel as pilot fuel, has been examined. At moderate and relatively high loads, the results show very interesting behavior of dual fuel operating mode in comparison to conventional diesel, both for engine performance and emissions. It showed a simultaneous reduction of soot and NO_x species over a large engine operating area. Moreover, it showed the possibility to obtain lower BSFC (brake specific fuel consumption) than conventional diesel engine. However, this mode presents some deficits at low loads, especially concerning unburned hydrocarbons and carbon monoxide emissions. Understanding those deficiencies is a key of such engines improvement. Some suggestions for new measures towards DF mode improvement are deduced.

1. Introduction

NG (Natural gas) is one of the most promising available fuels for internal combustion engines. Few alternative fuels offer the distinct and attractive advantages of natural gas [1]. Recently, environmental and economical concerns have motivated many governments to consider natural gas as fuel for passenger vehicles as well as stationary engines [2]. A promising technique for its use in internal combustion engines is the dual fuel concept [3].

In dual fuel engines, the gaseous fuel is inducted along with the intake air and is compressed like in a conventional diesel engine. The air-gaseous fuel mixture does not autoignite due to its high autoignition temperature limit [4]. A small amount of neat diesel or biofuel [5,6] is injected near the end of the compression stroke to ignite the gaseous mixture. Diesel fuel autoignites and creates ignition sources for the surrounding air–gaseous fuel mixture. The pilot liquid fuel, which is injected by the conventional diesel injection system, contributes only with a small fraction in the engine power output [7].

The dual fuel engine has been employed in various applications with different gaseous fuels due to their cleaner combustion compared to conventional liquid fuels [8,9]. However, natural gas seems to be an excellent candidate because of its worldwide usage. It has a high octane number, and therefore, it is suitable for engines with relatively high compression ratios. It mixes uniformly with air, resulting in efficient combustion and a substantial depletion of some emissions in the exhaust gas [3]. Moreover, it is possible to apply this technology on existing diesel engines with minor modifications. The potential benefits of using natural gas in diesel engines are both economical and environmental.

However, to be more attractive, some aspects must be improved for best performance and less emissions [10]. One of the main problems with dual fuel operating mode is that, at low load, the engine efficiency decreases compared to conventional diesel. The unburned hydrocarbons and carbon monoxide emissions are also higher in dual fuel mode [4,11,12].

Some experimental and theoretical investigations concerning the dual fuel operating mode using natural gas have been reported in specialized literature [4,13,14]. The effect of some engine parameters, such as injection timing [15,16], pilot diesel fuel amount [17], gaseous fuel – air mixing system [18], air inlet preheating and EGR (Exhaust Gas Recirculation) [19] on the engine performance were also examined. It was found that improvements in engine

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performance and reduction in some emissions can be achieved by optimization of some parameters such as advancing the injection timing or increasing the amount of pilot fuel. EGR with intake heating can also be a promising solution for improving engine efficiency and reducing CO, THC (total hydrocarbon) and NO_x emissions.

The present study aims to examine the effect of dual fuel mode on combustion characteristics, engine performance and exhaust emissions. Experimental investigations are used to achieve this work and the obtained results aim first, to identify the engine operating conditions which are able to provide mechanical and environmental benefits within this mode.

A conventional DI (direct injection) diesel engine has been properly modified to operate in dual fuel mode. The engine is first operating in conventional mode with neat diesel fuel, then in dual fuel mode in order to achieve a real comparison. The obtained results are compared with previous studies to better understand such operating mode (dual fuel) and related problems, so that to make conclusions and recommendations which can aid for improving the natural gas dual fuel operating mode.

2. Experimental setup and experimental procedure

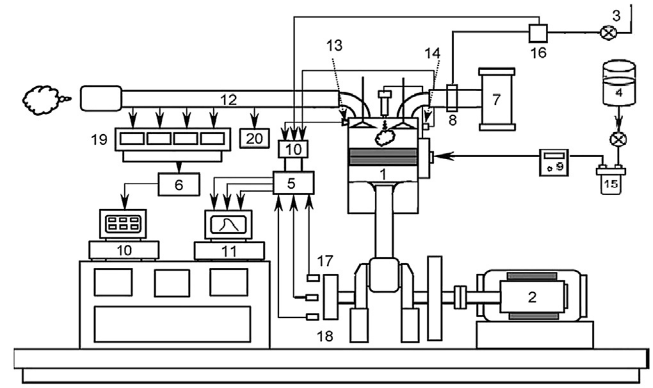
2.1. Engine test cell

A single cylinder air cooled Lister Petter (TS1) diesel engine with output power of 4.5 kW at 1500 rpm is used to carry out engine tests. The basic data of this engine are given in Table 1. The experimental set up scheme is shown in Fig. 1. The engine is connected to an automatic controlled eddy current dynamometer. An orifice meter connected to a large tank is attached to the engine for air flow measurements. The diesel fuel flow rate is measured with a Coriolis type flow meter. Chromel alumel thermocouple in conjunction with a slow speed digital data acquisition system is used for measuring the exhaust gas temperature.

To carry out dual fuel engine experiments, the engine was conveniently modified. It is supplied with natural gas from the local distribution network. Natural gas flow rate is measured using a thermal flow meter (Bronkhorst F112AC-HB-55V). Adjustment of gaseous fuel supply is accomplished through a control valve. Then, the gaseous fuel is mixed with the air in the engine intake manifold. The composition of natural gas used in the present tests is given in Table 3.

2.2. Combustion data acquisition

A rapid digital data acquisition system (AVL – Indiwin) in conjunction with two AVL piezoelectric transducers is used to get the in-cylinder and diesel fuel injection pressures. The data from 100 consecutive cycles at an increment of 0.1 crank angle, are recorded and averaged, with a specific AVL software, to obtain combustion parameters [11,20,21]. An optical shaft position encoder AVL 364C is used to determine the angular position and the engine rotational speed.



1. Test engine
2. Dynamometer
3. Gaseous fuel supply
4. Gasoil tank
5. A/D card for pressure
6. A/D card for Analyzer
7. Air tank
8. Air-gas Mixer
9. Diesel flow meter
10. Charge Amplifier
11. Fast data acquisition system
12. Slow data acquisition system
13. Cylinder pressure sensor
14. Injection pressure sensor
15. Liquid fuel filter
16. Gaseous fuel flow meter
17. TDC encoder
18. Speed sensor
19. Exhaust gas analyzer
20. Smoke meter

Fig. 1. Experimental setup scheme.

2.3. Emission instrumentation

Unburned HC (hydrocarbon) species are captured using the FID technique from sampling exhaust gas. The NO and NO_x concentrations in the exhaust gas are measured with the chemiluminescence technique using a TOPAZE 32M analyzer. Carbon monoxide (CO) and carbon dioxide (CO_2) concentrations are measured by infrared radiation absorption using a MIR 2M analyzer. Oxygen (O_2) concentration is given by a paramagnetic sensor. Smoke levels are observed continuously using the smoke meter (TEOM 1105).

Table 1
Engine specifications.

Constructor	LISTER-PETER (TS1)
Engine type	4 strokes, compression ignition, diesel direct injection (DI)
Number of cylinders	Single cylinder
Bore × stroke	95.5 × 88.94 mm
Volumetric capacity	630 cm^3
Compression ratio	18
Injection	13° CA before TDC
Injection pressure	250 bars
Power output	4.5 kW at 1500 rpm
IVO	36° CA before TDC
IVC	69° CA after BDC
EVO	76° CA before BDC
EVC	32° CA after TDC

Table 2
Accuracy of measuring instruments and uncertainty of computed parameters.

Parameter	Measuring instruments	Accuracy
Torque	Effort sensor	±0.1 Nm
Engine speed	AVL 364C	±3 rpm
Injection timing	AVL 364C	±0.05° CA
Intake air flow rate	Differential pressure transmitter (LPX5841)	±1% of measured value
Fuel flow rate	Coriolis type mass flow meter (RHM015)	±0.5% of measured value
In cylinder pressure	Piezo-electric (AVL QH32D)	±2 bars
Injection pressure	Piezo-electric (AVL QH33D)	±2 bars
Intake air temperature	Differential pressure transmitter (LPX5841)	±1.6 K
Exhaust gas temperature	K type thermocouple	±1.6 K
Ambient air temperature	HD 2012 TC/150	±0.2 K
Relative humidity	HD 2012 TC/150	±2%
$CO/CO_2/O_2$	MIR 2M	±2% Full scale
NO_x	TOPAZE 32M	±2% Full scale
THC	GRAPHITE 52M	±2% Full scale
Soot emissions	TEOM 1105	±30 ng/s
Computed parameters		Uncertainty
Brake power	–	±1.9%
BSFC	–	±2%
Fuel air Eq. ratio	–	±1.1%