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Effects of oxygen enriched air on the operation and performance of a diesel-biogas dual fuel engine

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ABSTRACT

The effect of oxygen enriched air was tested for a diesel-biogas dual fuel engine. The operation and performance characteristics, such as thermal efficiency, pollutant emissions and combustion parameters were determined. Experiments have been carried out with a stationary compression ignition (CI) engine coupled with a generator in dual mode using a typical biogas composition of 60 vol. $\%CH_4$ and 40% vol. $\%CO_2$. For every engine load evaluated, the oxygen concentration in the intake air engine was varied from 21% to 27% O_2 v/v. Ignition delay time and methane emissions were decreased when using oxygen enriched air with respect to normal air ($21\%O_2$), whereas the thermal efficiency was increased.

1. Introduction

Biogas is an alternative energy source and it is produced from anaerobic fermentation of organic material. It is a low heating value fuel and methane and carbon dioxide are its main components. Rural households use biogas for cooking, while farms normally go for heat, shaft power and electricity generation. Because of its high octane number, biogas is suitable for engines with a relatively high compression ratio to maximize thermal efficiency and may be applied to conventional compression ignition engines with minor modifications [1].

A dual fuel engine is a diesel engine operating with gaseous fuels while maintaining some liquid fuel injection as source of ignition. The main objective of dual engines is to reduce the use of fossil fuels and maximize their substitution with alternative fuels, in attention to economic and environmental reasons [2].

There are some problems associated with the performance of dual engines. At light load, the dual engine tends to exhibit lower fuel utilization, low thermal efficiency, higher pollutant emissions and long ignition delay. This is due to low ignitability of gaseous fuels like methane and the dilution with CO_2. On the other hand, operation at light load is associated with a greater degree of cyclic variations in performance parameters, such as peak cylinder pressure and ignition delay. The principal cause of this behavior is the low flame propagation velocity from the pilot fuel ignition into the lean gaseous fuel mixture [3].

Ignition delay is a critical parameter to control the performance and emissions of internal combustion engines. In dual engines, ignition delay increases due to a reduction in the partial pressure of oxygen in the intake air, reduced reaction activity because of the inert in the fuel, and changes in the effective temperature during compression. A long and

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variable ignition delay time is undesirable as it leads to an increase in the premixed part of combustion in a heat release diagram. This produces the reduction in engine efficiency, increase in exhaust emissions, and damage in mechanical parts [3–7].

Many research efforts have been done to provide effective solutions for further improvement of dual operation at light load. Such solutions include changes in the initial charge temperature and pressure, quantity and quality of liquid fuels, air-fuel ratio, and injection characteristics of liquid fuels such as increasing injection pressures. All these measures cause increases in thermal efficiency and decreases in pollutants emissions and ignition delay times [3,8–11].

Another possible and simpler solution to improve the operation of dual diesel engines at light load is the increase of oxygen concentration in the air intake up to 30% O_2 by volume. This has shown successful results in spark ignition and compression ignition engines such as increases in power density, thermal efficiency and decreases in pollutants emissions [12–15]. All of these effects are due to increase in burning velocities. However, NO_x emissions were increased due to higher temperatures inside the combustion chamber [16–18]. Other researchers have conducted experiments with oxygen concentrations below 24% O_2 by volume. For oxygen concentrations up to 23%, the particulate matter decreased as well as the ignition delay, and NO_x emissions were in a permissible range [12,19,20]. Additionally, the combination of water-diesel emulsions and oxygen enrichment (24% molar) was assessed. An increase of 10% in effective efficiency decreases in particulate matter and a low increase in NO_x emissions were obtained at full load [19].

In spark ignition engines with oxygen enriched air and gasoline as fuel, several researches found a decrease in carbon monoxide and hydrocarbon emissions, and an increase in the effective power in whole range operation [14,21–23]. Maxwell, Setty, Jones and Narayan [23] worked with oxygen concentrations in air of 23%and 25% O_2 v/v in a spark ignition engine fueled with gasoline and natural gas. An Increase in effective power by 5–17%, a decrease in carbon monoxide emissions by 25–32%, as well as a decrease in hydrocarbons by 30–40% were obtained.

There are several processes currently available for producing oxygen. The most efficient at large scale is cryogenic air separation. Pressure-swing absorption is used at medium to small scale. The most common method to deliver air enriched with oxygen to engines is selective permeation through nonporous, polymeric membranes. However, their costs are higher and their operation requires high pressures, resulting in additional cost of the engine tests [21,24]. Because of the recent progress in nonporous polymeric membrane methods to enhance oxygen in air and the reduction in their production costs, this solution will be technically and economically feasible in few years [13–15,21,25–31].

It is expected that the use of oxygen enriched air in a biogas-diesel dual engine attenuates the effect of CO_2 in decreasing the laminar burning velocity, adiabatic flame temperature and ignition delay time of methane [32]. Moreover, an increase in thermal efficiency and a decrease in pollutants emissions are expected. However, information about this issue for dual diesel-biogas engines is limited in literature. Therefore, in this study the results of the effect of varying the concentration of oxygen from 21 to 27% O_2 by volume in a dual diesel-biogas engine are discussed.

2. Experimental methodology

2.1. Experimental setup

The experimental tests were performing at a region placed at 1500 m over the sea level (Medellín – Colombia). The local environmental conditions were 298 K and 85.3 kPa. A stationary CI engine was coupled with a generator to run at maximum torque speed (1800 rpm). Table 1 shows the technical engine characteristics [33].

The experimental work started with preliminary investigation of the engine running on neat diesel fuel, in order to determine its performance characteristics. Electric power outputs at 40%, 50%, 70% and 100% of full load were obtained. Engine loads were set from 3 to 10 kW with a variable electrical resistance bank connected to the electricity generator.

In the dual fuel mode, Colombian commercial diesel was used and biogas was simulated with a typical composition of 60% CH_4 and 40% CO_2 on a volumetric basis. The flow rate of CO_2 and CH_4 were both measured with hot wire sensors (Omega; FM5400). The flow rate of diesel fuel was measured with Coriolis sensor (Siemens; SITRANS 2100 DI). Table 2 summarizes important properties of the fuels used in the experiments.

The load of the engine was fixed and the biogas was injected into the air intake manifold using a “Tee” mixer at a point that ensures homogenous mixture. Parameters such as power produced by the engine, engine speed, fuel consumption, air flow, temperatures and emission characteristics were measured.

Oxygen (99.9% O_2) from gas bottles was injected in counter flow via a tube with three orifices into the air intake manifold. The air composition in a volumetric basis was measured at the duct using a gas analyzer with the paramagnetic technique (MAIHAK S710). An orifice meter and a U-tube manometer were used to measure the air consumption of the engine.

The in-cylinder pressure was measured using a piezoelectric pressure transducer (Kistler; model: 6125B) which was flush mounted in the cylinder head. The air intake pressure was measured with a piezoresistive pressure

Table 1 – Test engine characteristics.

Type	Lister Petter TR2, DI, four stroke, two cylinders, naturally aspirated, air cooled
Displacement	1.55×10^{-3} m^3
Bore × stroke	0.098 × 0.101 m
Compression ratio	15.5:1
Rated power	20 kW at 3000 rpm
Maximum torque	76 Nm at 1800 rpm
Inlet valve open	36° BTDC (Before Top Dead Center)
Exhaust valve close	32° BTDC