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COB-2023-1913 ANALYSIS OF DUAL FUEL OPERATION WITH CONSTANT LOAD IN A COMPRESSION IGNITION ENGINE

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Abstract. *The utilization of alternative fuels in internal combustion engines has received considerable attention in recent years due to the need for sustainable and environmentally friendly energy sources. This study focuses on the concept of dual-fuel combustion, specifically the combination of diesel fuel and ethanol, in a compression ignition engine. Ethanol, a renewable fuel source, also helps to reduce fossil fuel dependence and greenhouse gas emissions. In this study, the ethanol is injected into the intake manifold while the diesel fuel is injected directly into the combustion chamber. The engine used is a single-cylinder research engine that allows operation with two fuels. Diesel oil serves as the ignition fuel, which ignites the ethanol-air mixture. A constant IMEP value was specified for these tests. To meet this requirement, the mass of diesel injected into the pilot injection was kept constant, while it was gradually reduced in the main injection. As the diesel from the main injection decreased, ethanol was injected with an appropriate pulse to maintain the same IMEP value. The main objective of this study is to analyze the acceptable substitution rate of ethanol in a diesel engine and the emissions resulting from combustion. However, the implementation of diesel and ethanol dual-fuel engines requires careful calibration of injection timing and rates to ensure optimal performance and emissions.*

Keywords: *Diesel engine, Dual fuel, Emissions, Soot.*

1. INTRODUCTION

Fuel demand is expected to increase over the next three decades, and fossil fuels are estimated to account for 80% of energy consumption in 2050 (Energy Information, 2019). The development of more efficient engines and systems to reduce emissions is the focus of research worldwide. Compression ignition (CI) engines, known for their efficiency and robustness, are widely used in various applications such as passenger cars, trucks, agriculture, and power generation.

The emission of particulate matter (PM) and nitrogen oxides (NOx) is the main problem associated with the use of diesel engines (Heywood, 1988). These gasses are mainly responsible for global warming and climate change (Panahi et al., 2019). Many researchers have focused on the use of ethanol-diesel blends in compression ignition engines to reduce emissions while maintaining comparable efficiency, thereby reducing some of the reliance on conventional diesel fuel (Paul et al., 2013).

One strategy to directly reduce engine emissions is through advanced combustion processes such as low-temperature combustion. These approaches are considered promising for improving the efficiency of CI engines while reducing NOx and PM emissions. The use of alternative and cleaner fuels could be one strategy to achieve this objective (Ianniello et al., 2013). Ethanol is considered one of the most promising alternative fuels for diesel engines, because it can significantly contribute to the reduction of particulate emissions in the exhaust (Di Blasio et al., 2013).

First-generation ethanol can be produced through the direct fermentation of sugars, such as sugarcane and sweet beet, making it a biofuel. Additionally, it is possible to obtain second-generation ethanol, which uses low environmental impact raw materials that would otherwise be discarded. Among these raw materials are plant residues, such as straw, leaves, pulp, chips, and others.According to Imran et al. (2013), there are several methods for using ethanol-diesel blends in CI engines. When ethanol is blended with diesel, the fuels are premixed in the tank and directly injected into the combustion chamber. Chauhan et al. (2010) explain that the proportion of ethanol in the blend is limited due to its low density and viscosity. Thus, the mixture of diesel and ethanol should not exceed 15% to ensure normal engine operation without modifications (Chauhan et al., 2010). The use of ethanol in PFI (port fuel injection) compression ignition engines, known as fumigation, is a technique that stands out among others, as it allows for high substitution rates of ethanol (Hansdah and Murugan, 2014). The PFI technique has the advantage of requiring minimal engine modifications, and facilitating testing. The literature reports that the presence of ethanol decreases NOx emissions but increases CO emissions. This behavior occurs because the use of ethanol in PFI decreases the combustion temperature, which reduces NOx formation but leads to incomplete combustion, which in turn leads to increased CO emissions.

Therefore, this study endeavors to explore the utilization of ethanol in a dual-fuel injection mode alongside diesel, with ethanol serving as a partial fuel in a single-cylinder compression ignition engine. Consequently, we will vary the ethanol quantity to assess the feasibility of substituting diesel with ethanol, thereby mitigating exhaust emissions and reducing our reliance on fossil fuels.

2. EXPERIMENTAL PROCEDURE

A single-cylinder AVL 5402 (Figure 1) compression-ignition research engine coupled to an active ac dynamometer was used for the experiments. The engine characteristics are listed in Table 1.

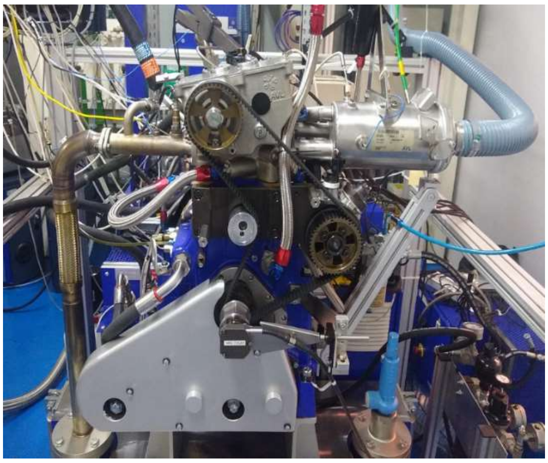

Figure 1 – Single cylinder engine.

Table 1: Engine characteristics.

Component	Value	Unity
Number of Cylinders	1	-
Cylinder Bore	85	mm
Stroke	90	mm
Swept Volume	511	cm³
Number of Valves	3	2 Inlet, 1 Exhaust
Compression Ratio	17.3	-
Fuel	Diesel	-
Fuel System	Direct Injection	-

In addition to the diesel injector Table 2, an ethanol injector was installed in the intake port to enable the dual-fuel mode. The PFI injector chosen was the IWP 308 model, from MARELLI (Figure 2), which has the characteristics described in Table 3.

Table 2 – Parameters of the diesel injetor nozzle.

Part Number	Bosch 0 445 110 646
Number of Holes	8
Hole Diameter	0.122 [mm]
Pressure Limit	2200 [Bar]

Table 3 - Parameters of the PFI injector nozzle.

Injector	IWP 308
Injection holes	4
Operating pressure	2.5 bar

Figure 2 - IWP 308 injector nozzle.

Therefore, an adapter for the PFI injector was designed to allow the injector to be mounted as close as possible to the inlet valves to ensure proper vaporization since hydrous ethanol has a high enthalpy of vaporization and requires downstream air conditions in the port to vaporize.

The adapter was designed considering the direction of the previously characterized spray, guided to the inlet valves at the same time allowing for easy assembly and disassembly of the injector (Figure 3). Figure 4 shows the adapter mounted on the engine.

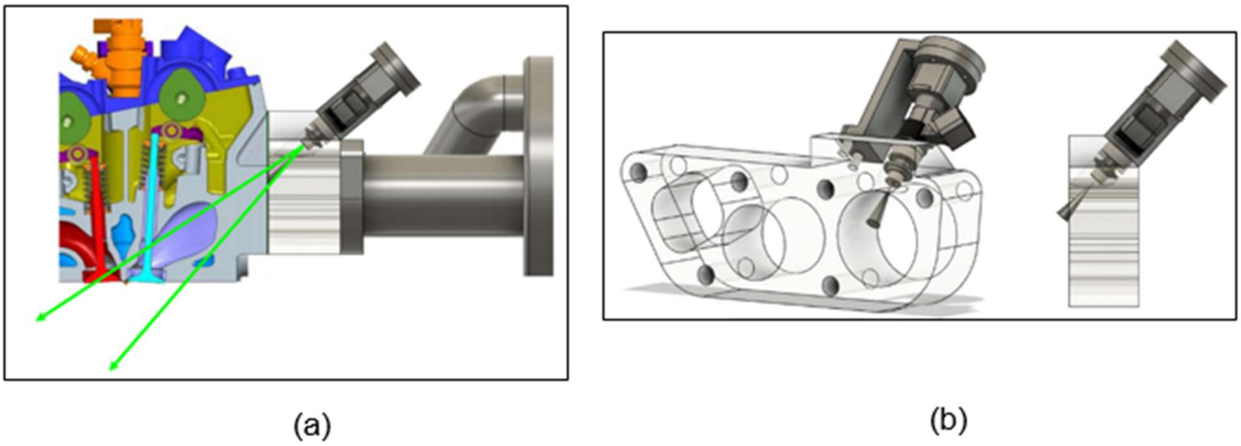

Figure 3 - (a) Analysis of spray angle integrated into the cylinder head, (b) Adapter for installing the PFI injector close to the intake valves.

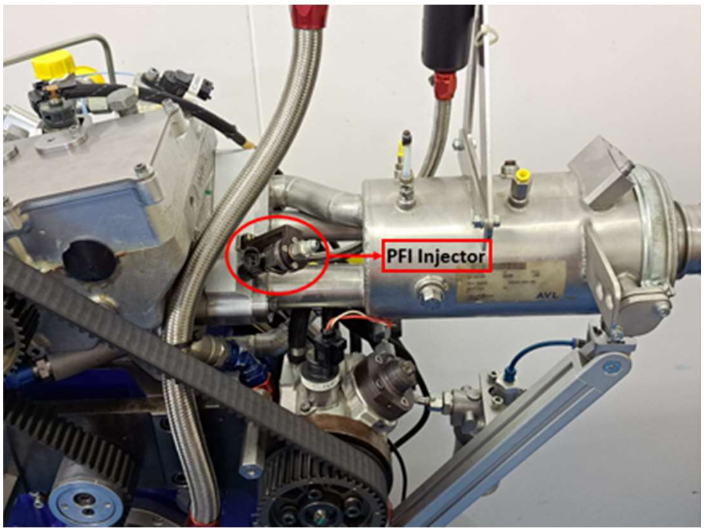

Figure 4 - PFI injector adapter mounted on the engine.

After the adapter was installed, the test parameters (baseline) were set for diesel operation (100% diesel baseline). For this study, a value of approximately 7.2 [bar] was set for IMEP, which is considered a high load for this engine. Testes were then conducted with the injection of ethanol in the intake manifold (injection timing of 240° BTDC), maintaining the same diesel injection timing for main and pilot injections used in the reference tests. A speed of 2500 rpm was used for all tests, as this is a common speed for passenger car diesel engines. The other parameters used are listed in Table 4.

To meet the constant load requirement, the mass of injected diesel was kept constant during pilot injection, while in the main injection, it was gradually reduced. When the diesel was reduced in the main injection, ethanol was injected with an appropriate pulse to maintain the same IMEP value.

Table 4 – Test parameters for 2500 rpm.

Parameters	Dual-Fuel
Speed	2500 rpm
Injection pressure [bar]	1300
SOI pilot [°ca]	27
SOI main [°ca]	7.87
DOI pilot [mg/st]	2.47
DOI main [mg/st]	26.8 to 22.2
Injection Pressure pfi [bar]	2.5
SOI PFI [btdc]	240
DOI PFI [mg/st]	2.12, 4.015, 5.4, 6.75 and 8.22
Blend AFR	14.4:1

3. RESULTS

Three repetitions were performed for each condition and for each one the results were collected for sixty seconds, in order to maintain the reliability of the results obtained.

The behavior of AI50% (50% of mass fraction burned) (Figure 5) shows that as the substitution rate increases, combustion is delayed compared to operation with 100% diesel. This phenomenon can be explained by the fact that when ethanol is injected into the intake manifold, it reduces the temperature of the gas entering the cylinder, causing the air/fuel mixture to take longer to ignite, resulting in a delay in combustion.

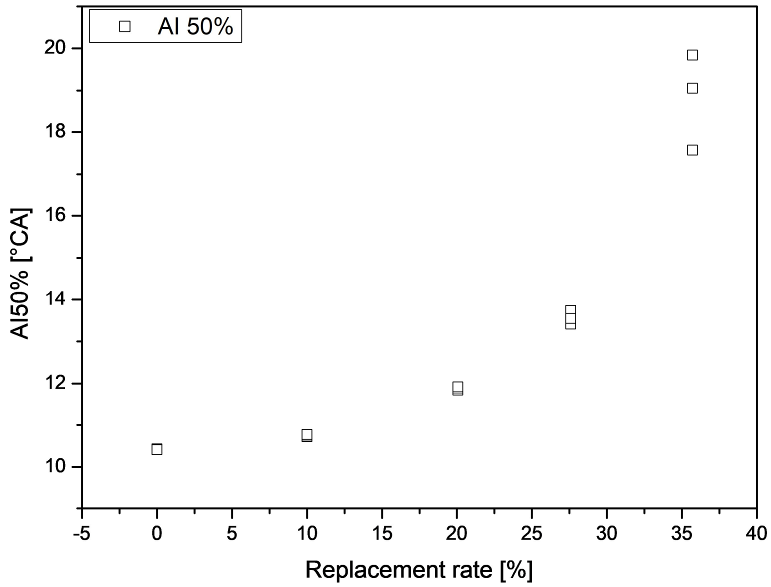

Figure 5 - Behavior of the AI50% with the increase in the replacement rate.

Figure 6 shows that when ethanol is injected, the peak pressure in the cylinder gradually increases up to a 20% substitution rate. Beyond this point, the cylinder pressure begins to decrease. This behavior may be related to the air, diesel, and ethanol mixture is rich at the time of ignition. This rich mixture leads to more fuel burning in the premixed phase, resulting in an increase in peak pressure and heat release (Figure 7), as well as a delay in combustion (Zhang et al., 2013).

An increase in the ethanol concentration resulted in a greater ignition delay and a higher energy release in the premixed phase of combustion up to a 27.6% substitution rate. This can be explained by the fact that ethanol has lower density and viscosity compared to diesel. These factors facilitate better fuel atomization and formation of the air/fuel mixture (Hulwan and Joshi, 2011), resulting in rapid combustion of a larger quantity of fuel in the premixed phase and a quick release of heat, increasing in peak pressure and heat release rate (Zhu et al., 2011).

However, at a 35.7% substitution rate, the peak pressure and heat release rate were found to be lower than the baseline mode. This behavior may be attributed to the large amount of ethanol injected, which reduces the temperature of the mixture and causes a delay in combustion, consequently leading to a decrease in peak pressure and integral heat release.

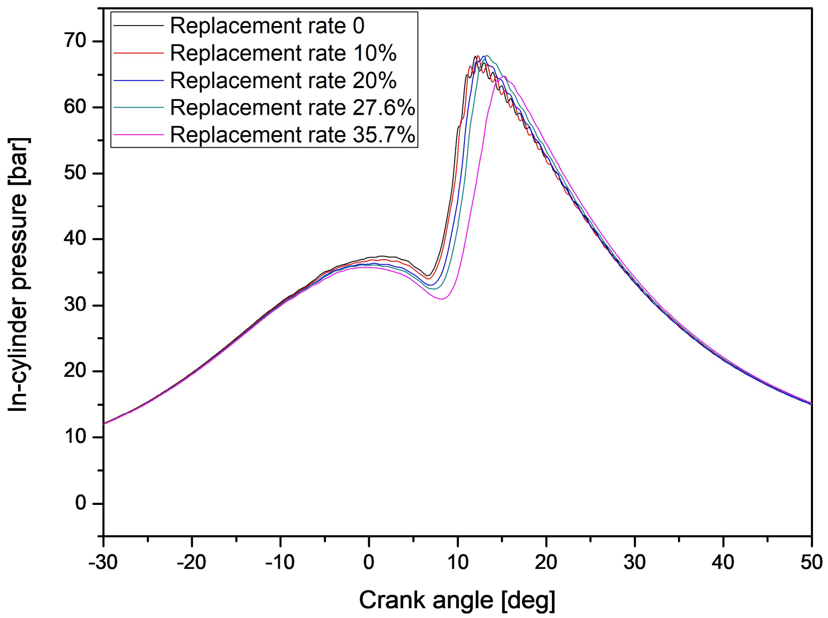

Figure 6– Cylinder pressure behavior with increasing replacement rate.

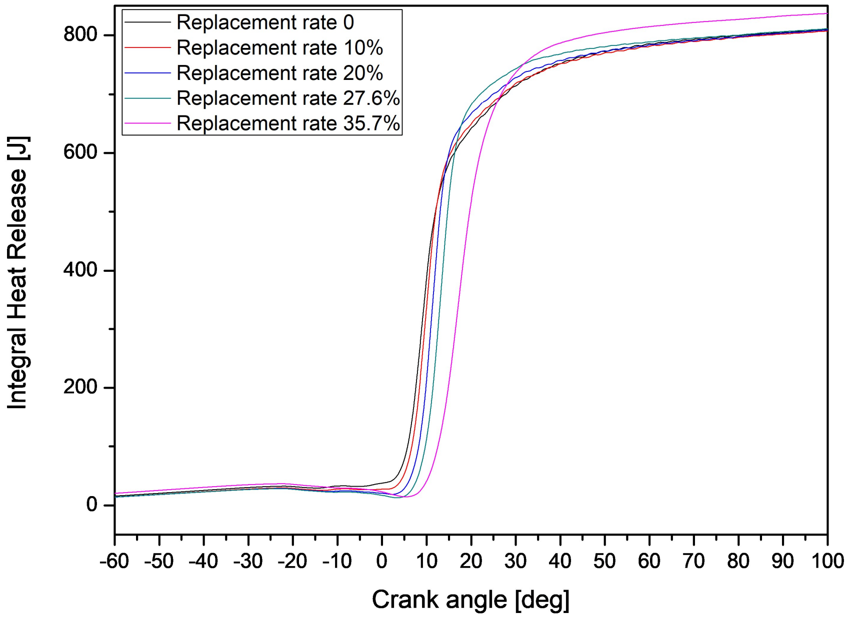

Figure 7 – Heat release with increasing replacement rate.

In Figure 8, a significant increase in aldehyde emissions can be observed in the diesel-ethanol operation compared to 100% diesel operation. The emissions of formaldehyde and acetaldehyde tend to increase as the formation principle is enhanced with incomplete combustion of hydrocarbons and lower combustion temperatures (Brito and Martins, 2015).

The oxidation of aldehydes is favorable at higher temperatures, above 850 K (Wagner and Wyszynski, 1996), thus their formation tends to be higher under conditions of lower operating temperatures. In this study, it was observed that during diesel-ethanol operation, temperatures were lower, which may lead to partial oxidation of the fuel without reaching the temperature required for complete reaction. The high latent heat of vaporization of ethanol tends to result in slow vaporization, leading to low homogeneity between the air/fuel mixture, contributing to an increase in HC (Figure 9) and consequently aldehydes (Reitz, 1989).

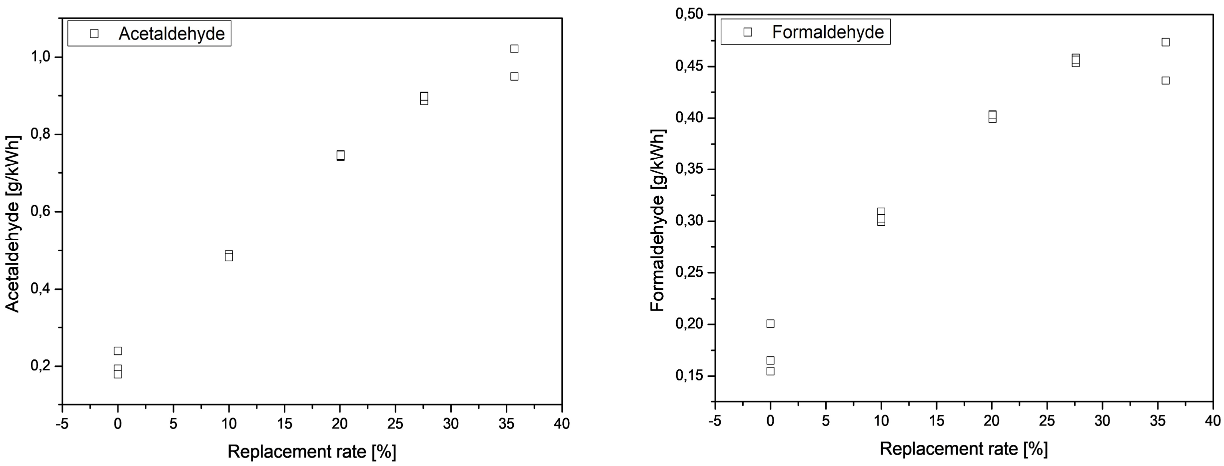

Figure 8 – Formation of aldehydes with increasing replacement rate.

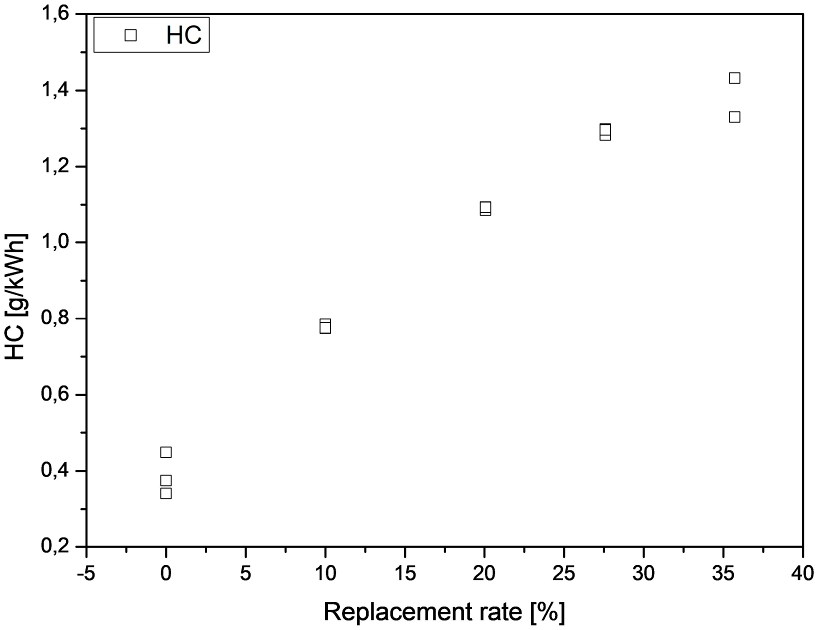

Figure 9 – Behavior of hydrocarbons with increasing replacement rate.

The formation of NOx in a diesel engine depends on the combustion temperature, along with the concentration of oxygen present in the combustion process. When ethanol is injected, the combustion temperature can decrease, leading to a reduction in NOx formation, especially under fuel-lean conditions. However, under high engine loads, as in the case of this study, increased ignition delay and a richer mixture tend to reduce the cooling effect, increase NOx formation (Figure 10).

Figure 11 shows that soot formation decreases as the substitution rate increases. It is well that diesel, has a high tendency to form soot due to the nature of its combustion process. Therefore, the presence of ethanol in a diesel engine increases the oxygen content in the mixture, which reduces soot formation under normal engine operating conditions. Sinha and Thomson (2004) concluded that the presence of oxygen in the oxygenated fuel, which is injected by spraying along with diesel, can contribute to the reduction of the primary soot precursor, acetylene. The reduction of acetylene occurs due to the presence of additional oxygen atoms in the rich mixture regions within the flame, which, in turn, reduction the amount of soot during combustion.

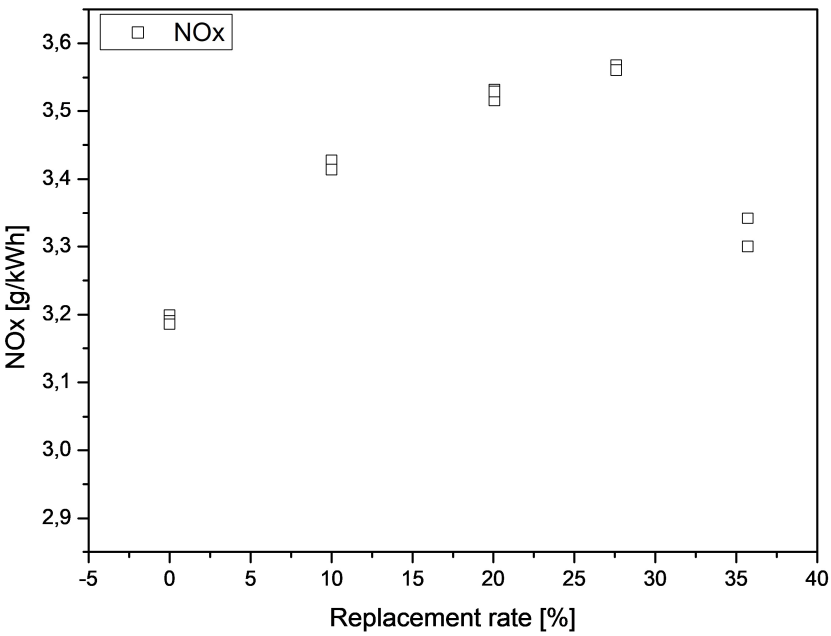

Figure 10 - NOx behavior with increasing replacement rate.

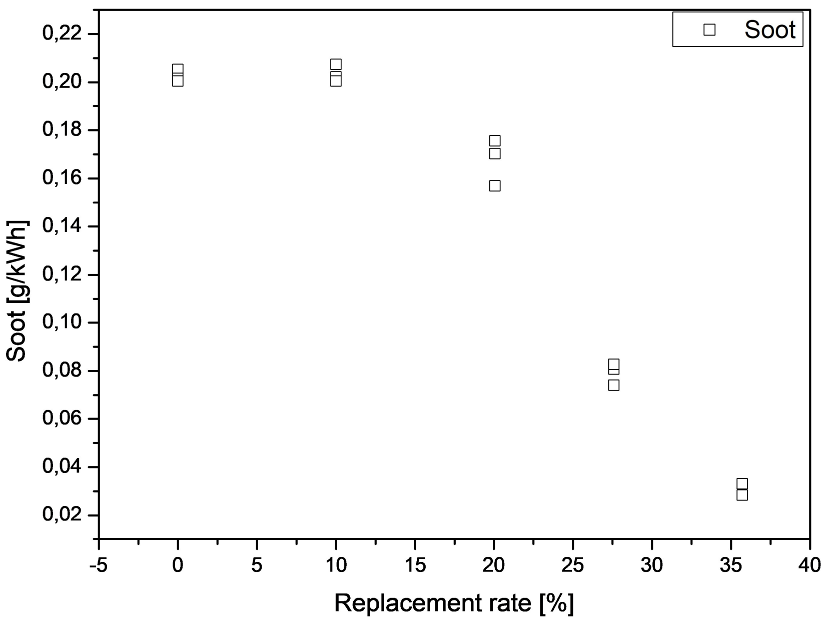

Figure 11 – Soot behavior with replacement rate.

4. CONCLUSION

In this study, it was observed that the presence of ethanol causes a delay in combustion. Furthermore, ethanol resulted in an increase in cylinder pressure and heat release rate up to a certain replacement rate. In addition, the tests showed that despite the higher heat release rate, aldehydes, unburned hydrocarbons, and NOx increased when the substitution rate was increased. However, soot formation decreased by 83.5% at the higher replacement rate compared to operation with 100% diesel.

5. ACKNOWLEDGEMENTS

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