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POLLUTANT EMISSIONS INVESTIGATION IN A COMPRESSION IGNITION ENGINE DURING WARM-UP TIME

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Abstract. *Environmental restrictions about pollutant emissions on reciprocating engines become tighter over the last decades. Various investigations were conducted to assess the emissions of pollutants for both spark and compression ignition engines. However, the large majority of these studies were carried out in steady state conditions. This paper aims to publish the assessment of a single-cylinder compression ignition engine during its warm-up time. Data were acquired during the time elapsed for the exhaust gases temperature achieves the steady condition. In addition, the tests were repeated in more three different loads. Results shows the variation in temperature, nitrous oxides, carbon monoxide and unburned hydrocarbons related to both: elapsed time and increase of load.*

Keywords: *diesel engine, pollutant emissions, warm-up time*

1. INTRODUCTION

In 1986, the Brazilian Environmental Agency (CONAMA) created the Air Pollution Control Program for Automotive Vehicles (PROCONVE), which aimed to implement regulatory laws and targets for vehicle manufacturers in order to decrease pollutants emitted by such vehicles, and subsequently leading to the reduction of directly associated environmental impacts.

The main pollutant gases emitted by the engine are carbon monoxide (CO), unburned hydrocarbons (UHC) and nitrogen oxides (NO_x). While NO_x formation are related to high temperature (Turns, 2013), the presence of CO and UHCs means that an inefficiency in combustion takes place (Bahr, 1972 and Söhret et al., 2015). This paper assesses the behavior of these three pollutants during the time elapsed by a diesel engine to warm-up.

Cold start in CI engines can be serious problem due the low temperatures (Stone, 1999). Both CO and UHC are products of incomplete combustion reaction. The incompleteness of the combustion process takes place due the low temperatures spots which can appear in combustion chamber, kidnapping an amount of energy which would be used to activate the oxidation reaction. Unburned hydrocarbons are organic compounds of unreacted fuel or spinoffs of intermediary reactions, which are present in exhaust gases (Marques et al., 2017). Furthermore, the presence of CO and UHCs in combustion products means that some fuel did not oxidize in the combustor (Silva et al., 2017). Thus there are some amount of the fuel energy which was not used by the engine. Still CO is an odorless and poisonous gas which, in high concentrations, can lead to death in less than one hour (Carvalho Jr. and Lacava, 2003).

Major NO_x formation happens due the Zeldovich mechanism and is also known as Thermal NO_x. It is strongly related to the temperature in the combustion chamber. NO_x can be responsible for acid deposition and smog formation.

2. MATERIAL AND METHODS

Tests were carried out using a single cylinder diesel-cycle engine driven generator. The alternate current generator was used as an electric dynamometer. Four pure resistive loads were used in order to vary the energy to be measured. A wattmeter was used to allow the readiness on the actual power delivery. A Greenline® 8000 flue gas analyzer was used. The analyzer probe was positioned at the exhaust pipe in order to collect the exhaust gas composition. A thermocouple assembled in the probe measured the temperature in the exhaust pipe and the ambient temperature was measured via a thermocouple in the gas analyzer main control unit.

All data collected was sent to the DBGas software in order to be assessed. Table 1 shows the engine and alternator specification. Figure 1 show the test rig.

Pollutant data acquired was standardized to 18% of oxygen presence in flue gases

Figure 1 shows: tachometer (1), engine driven generator (2), gas analyzer probe (3), auxiliary fuel reservoir positioned in the scale (4), flue gases analyzer.



Figure 1. Test rig

Table 1. Engine driven generator specification

Property	Value	Unit
Rated power	3.80	kVA
Engine	ATMA 178F	
Cylinders	1	-
Displacement	0.418	cm ³
compression ratio	9.8:1	-
Cycle	Diesel	-
Fuel	Diesel	-
constant rpm	3600	-
power factor	1.0	-
voltage	220/127	V

Table 2 summarizes the rig measurements and accuracies.

Table 2. Rig measurements and accuracies.

Measurement	Device	Accuracy	Unit
RPM	digital tachometer	1.00	rpm
time	digital stopwatch	0.01	s
power	Wattmeter	0.01	kW
temperatures	Thermocouple		
O ₂	electrochemical sensor	0.10	%
CO	electrochemical sensor	10.0	ppm
CO ₂	NDIR	0.30	%
NO _x	electrochemical sensor	5.00	ppm
CH ₄	NDIR	100	ppm

3. RESULTS AND DISCUSSION

Temperature was measured at the exhaust pipe. The steady state operation was seen when the flue gases temperature became stable. Figure 2 show the temperature increase during the warm-up time. It can be noticed that in all conditions the engine reached the operation temperature near 200 s. So for the following assessment the range from 0 to 300 s was considered. Figure 2 also shows that the exhaust temperature decreases as the demanded power increases. It evidences which more input energy was turn into work as the engine is demanded.

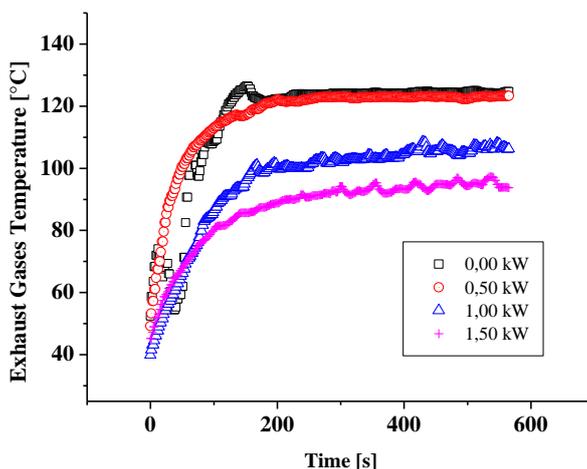


Figure 2: Exhaust gases temperature

Figure 3 show the NO_x. It was expected which the NO_x emissions follow the trend of the temperature raise. Nitrous oxides presence grows as the engine reaches the temperature of operation and its behaviour agrees with the Thermal or Zeldovich NO_x formation mechanism indeed. However in an odd way the NO_x presence raises even the temperature decreases in exhaust gases. In fact the pipe temperature behavior does not reflect that happens in the combustion chamber. As the power is delivered, the pressure in the combustion chamber also increases leading to a raise in temperature. Thus the higher is the power delivered the higher is the cylinder internal temperature causing a raise in the NO_x formation. The results also agrees with the thermal NO_x theory and it can be noticed which starts the engine in higher loads favors the nitrous oxides formation.

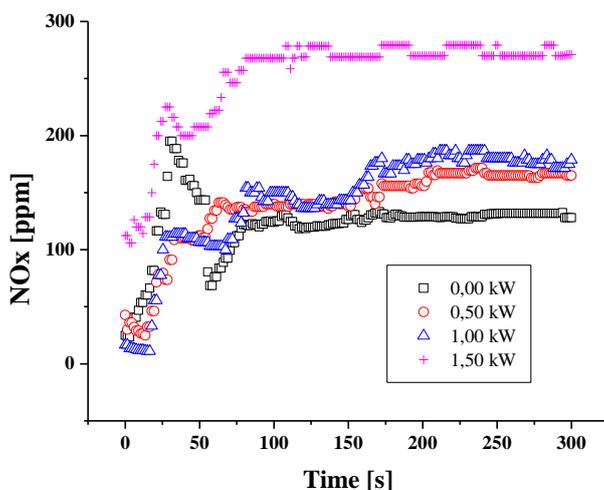


Figure 3: Nitrous oxides.

Both CO and UHC presence in the products means that some inefficiency in combustion reaction occurred. Unlike NO_x, is expected that its emissions decreases in higher temperatures. Figure 4 show the CO data acquired and Figure 5

show the behaviour of UHC during the warm-up time. As expected the behaviour is quite identical and demonstrates that the combustion efficiency increases as more load is demanded. Thus the presence of both in flue gases decreases as the engine was heated. Their behavior corroborates that the flue gases temperature varies inversely that the combustion chamber temperature.

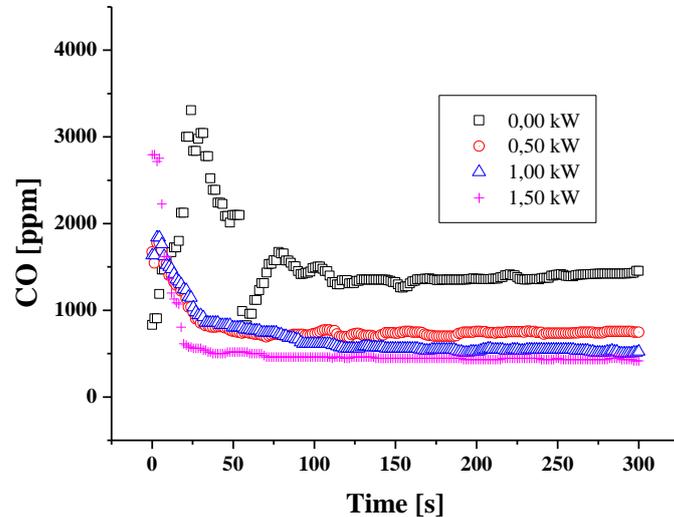


Figure 4: Carbon monoxide

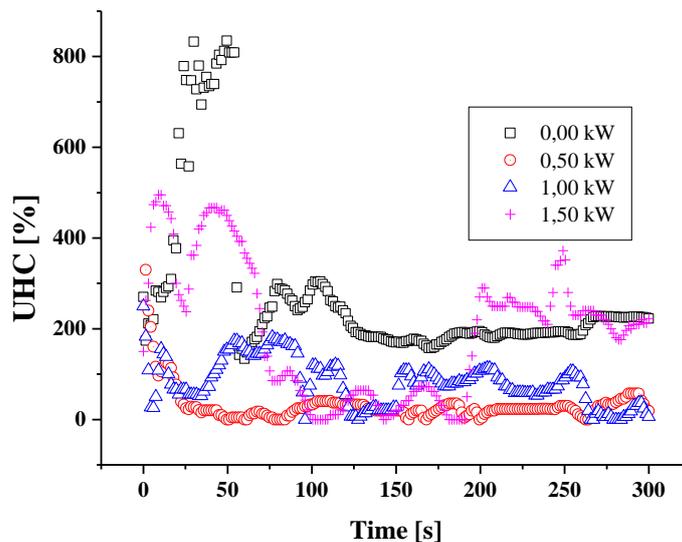


Figure 5: Unburned hydrocarbons.

4. CONCLUSIONS

Assessing the data acquired it can be concluded that.

1. The temperature of the exhaust pipe gases reached the steady state operation point nearly 200 s.
2. The temperature of the exhaust gases decreased when more load were demanded from engine. It means which more input energy was turn into work at the engine.
3. Nitrous oxides presence in flue gases raised as the engine went to the temperature of operation. It means that NO_x emissions are higher when the engine works in steady state operation than while it is warming. This fact agrees that the Zeldovich mechanism is the major contributor to NO_x formation in thermal machines.

4. Spuriously the observed NO_x emissions decreased as temperature increased. However the temperature was measured in the exhaust gases and the temperature is higher in combustion chamber as the engine is demanded. The higher is the power the higher is the internal combustion chamber temperature and the lower is that of the exhaust gases. This fact also reflects the importance of thermal NO_x formation mechanism.
5. Carbon monoxide emissions decreased as engine load is raised, it means that the combustion efficiency increased as the engine is required.
6. Unburned hydrocarbons emissions also decreased as the engine was demanded. This behaviour corroborates with the CO analysis.
7. Both CO and UHC presence in the exhaust gases decreased as the engine was warm-up. It also means which the combustion inefficiencies tends to decline when the engine reaches the temperature of operation.
8. The behaviour of the three pollutant emissions along the warm-up time agrees with their dependence on temperature.

5. ACKNOWLEDGEMENTS

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