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Warm-up time and number of tests for performance evaluation of a Diesel cycle engine

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ABSTRACT: *This research determined the engine warm-up time and the number of tests that must be carried out to obtain the performance parameters of a Diesel cycle engine. To this end, an agricultural tractor coupled to an eddy current dynamometer via a power take-off was used. Pure biodiesel (B100) was used as the fuel, and the hourly consumption was determined by means of a flowmeter. Data regarding torque, power, and hourly and specific fuel consumption was collected and analyzed at three engine warm-up times (20, 60, and 100 min). To determine the number of tests, 18 dynamometric tests were carried out to verify which of those presented the smallest experimental error, through the smallest coefficient of variation. No difference was observed in relation to the warm-up time for the analyzed variables, with a time of 20 min being enough to start the engine performance evaluations. In total, four trials were sufficient to assess engine performance and reduce experimental error.*

Key words: *dynamometry, agricultural tractor, biodiesel, torque, power.*

Tempo de aquecimento e número de ensaios para avaliação do desempenho de um motor de ciclo Diesel

RESUMO: *Este trabalho teve como objetivo determinar o tempo de aquecimento do motor e o número de ensaios que deve ser realizado para aquisição dos parâmetros de desempenho de um motor de ciclo Diesel. Foi utilizado um trator agrícola acoplado via tomada de potência a um dinamômetro de correntes parasitas. Como combustível, foi utilizado biodiesel puro (B100) e determinado o consumo horário por meio da utilização de um fluxômetro. Foram coletados e analisados os dados de torque, potência, consumo horário e específico de combustível, em três tempos de aquecimento do motor (20, 60 e 100 minutos). Para a determinação do número de ensaios, foram realizados 18 ensaios dinamométricos e verificado em quantos ocorre o menor erro experimental, por meio do menor coeficiente de variação. Pode-se observar que, não houve diferença com relação ao tempo de aquecimento para as variáveis analisadas, sendo que o tempo de 20 minutos foi suficiente para iniciar as avaliações de desempenho do motor; e o número de quatro ensaios representando serem suficientes para avaliar o desempenho do motor e reduzir o erro experimental.*

Palavras-chave: *dinamometria, trator agrícola, biodiesel, torque, potência*

INTRODUCTION

In Brazil, for more than 20 years, no official tests have been performed on agricultural engines. These tests determined torque, power, and fuel consumption, among other parameters that are important in the decision making process in the purchase of agricultural machinery. For these performance parameters to be evaluated, Diesel cycle engines must be subjected to tests with the use of dynamometric brakes (FIORESE et al., 2012).

Although, there are no official tests, educational and research institutions, as well as some agricultural machinery manufacturers, carry out dynamometric tests in order to obtain this information (NIETIEDT et al., 2011; DELALIBERA et al., 2012).

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Despite the existence of official norms, there is no standard time that is set to warm-up the engine to start the evaluations, nor is there a minimum number of tests required. Warming-up is necessary so that the internal components can work under ideal conditions, i.e., there is least possible resistance to the movement resulting from the expansion of the metallic components, which can interfere with the test results.

In experimental planning, the use of an adequate number of repetitions is important and must be considered. This number has been a common question among researchers (CARGNELUTTI FILHO & GUADAGNIN, 2011), to reduce the error and consequently, increase experimental precision (CATAPATTI et al., 2008). In judicious and intensive experiments, the greatest possible number of repetitions is key to having greater control over the experimental error, allowing for the identification of differences between treatments (STORCK et al., 2011). To estimate the accuracy of the experiments, a commonly used measure is the coefficient of variation (CV), which represents the standard deviation expressed as a percentage of the mean.

However, in the case of engine performance evaluation, a large number of tests increases the time and; consequently, the labor cost. After a certain number, there may not be a significant difference in the CV, and hence no further tests are required because the quality of the information obtained is not compromised statistically. However, for each response variable to be analyzed, there is a need to determine the number of repetitions, in this case, the number of tests.

In general, the greater the standard deviation of the observed data, the greater the number of repetitions should be. For quantitative variables, the increase in the coefficient of determination is not directly proportional to the increase in the number of repetitions since, after a given number of repetitions, the increase in the coefficient of determination becomes negligible as it reflects a minimal gain in the prediction of real data. In addition, the number of repetitions is determined through an analysis technique that minimizes costs and takes advantage of existing data to redefine or maintain experimental strategies (CARGNELUTTI FILHO & GUADAGNIN, 2011).

In this sense, research determined the engine warm-up time and the number of tests that must be performed to obtain the performance parameters of a Diesel cycle engine.

MATERIALS AND METHODS

Engine and fuel used in the research

The MF 4291 tractor (Massey Ferguson, Canoas, Brazil) was used in the experiment, equipped with a four-stroke turbocharged Diesel cycle engine, Perkins's brand, model 1104A-44T, with a displaced volume of 4400 cm³. According to the manufacturer's information, it has 77.2 kW (105 hp) of maximum power, under the ABNT NBR ISO 14396 (2011) standard.

The fuel used was pure biodiesel (B100) produced via the methyl route, composed of 80% soy, 15% bovine fat, and 5% pork fat, and provided by the company, *Olfar S/A - Alimento e Energia*, headquartered in the municipality of Erechim, RS. The physicochemical properties of the fuel are shown in table 1.

Before starting the experiment, the engine's fuel supply system was disconnected from the tractor's fuel tank and drained; and subsequently, connected to an external container with biodiesel, which became the system's power source.

Test method and procedure

The experiment was carried out following the ABNT NBR ISO 1585 (1996) standard, which corresponds to the ABNT NBR ISO 5484 (1985) standard. A dynamometric brake connected to the engine by means of a cardan tree was used, which connects the dynamometer to the tractor's power take-off. The dynamometer is an eddy current dynamometer, EGGERS brand, model PT 301 MES, with a braking capacity of up to 5800 Nm.

The angular speed and engine torque data are determined by means of sensors and transferred via Bluetooth to a notebook, on which the EGGERS Power Control software performs the receipt, treatment, and visualization of data, through a user interface. The power variable is calculated using torque and angular speed data. The specific hourly fuel consumption was determined by means of flowmeter, EGGERS brand, model FM3-100.

The tractor remained in the warming-up state for a period of 20 min in order to reach its optimum operating temperature quickly. For this, the engine was accelerated to the maximum angular speed, and after that, the dynamometer imposed enough braking to reduce the engine's angular speed by 25%. After the warming-up time was completed, the experiment began.

Before starting each test, the temperature and atmospheric pressure data were collected and entered into the software to correct the torque and power variables. The dynamometer was configured to perform a data reading at every 100 rpm drop in the engine's angular speed, starting from the first collection performed at 2350 rpm. Automatically, the dynamometer releases the brake when the engine

Table 1 - Physicochemical properties of the fuel used in the experiment.

Property	Result	Unity	Limit	Method
Aspect	C.F.I (22.3 ºC)	-	C.F.I(1)	Visual
Specific mass at 20 ºC	879.90	kg m^{-3}	850 – 900	ASTM D 4052
Kinematic viscosity at 40 ºC	4.11	mm² s^{-1}	3.0 – 6.0	NBR 10441
Water content, max.	188.90	mg kg^{-1}	380.0	EN ISO 12937
Total contamination, max.	23.60	mg kg^{-1}	24.0	EN 12662
Flash point, min.	159.00	ºC	100.0	NBR 14598
Ester content, min.	96.63	% mass	96.5	NBR 15764
Total sulfur, max.	2.20	mg kg^{-1}	10.0	ASTM D 5453
Cold filter clogging point, max.	3.00	ºC	5.0	ASTM D 6371
Methanol or ethanol, max.	-	% mass	0.2	EN 14110
Oxidation stability at 110 ºC, min.	8.91	H	6.0	EN 14112

Legend: (1) Clear and free of impurities with annotation of the test temperature.

torque starts to decrease, preventing the engine from turning off. Under the conditions of the experiment, considering the engine and the physicochemical properties of the fuel used (Table 1), the lowest angular speed recorded was 1150 rpm, for a total of 13 data collection points.

To determine whether the engine warm-up time influences the analyzed parameters, 18 dynamometric tests were divided into three groups, each corresponding to a particular warm-up time. In the first period, 6 tests were carried out, corresponding to a 20-min warm-up time. In the second period, 6 more tests were performed, corresponding to a 60-min warm-up time. In the third period, data from another 6 dynamometric tests were collected, which corresponded to a 100-min warm-up time.

Experimental and statistical procedures

Torque (Nm), power (kW), hourly consumption (L/h), and specific fuel consumption (g/kW.h) were analyzed in a bifactorial scheme (13×18), resulting from the interaction of 13 engine revolutions in the range of 2350 to 1150 rpm, and of the 18 dynamometric tests, totaling 234 treatments composing an experiment in a completely randomized design. All statistical analyses were performed using the R software (R DEVELOPMENT CORE TEAM, 2012) with the Agricolae package (MENDIBURU, 2012).

The homogeneity of the variance test was performed by means of the Bartlett test (BARTLETT, 1937). To test the normality of the residuals, the Shapiro-Wilk test (ROYSTON, 1995) was used. Once these conditions were met, the analysis of variance ($P \leq 0.05$) was performed to identify the differences between warm-up times. Furthermore, to better understand the interaction between the evaluated variables, a linear correlation analysis was performed between the engine performance parameters.

To determine the number of tests, the statistical CV parameter was used, and from the second repetition onwards, it is already possible to determine this coefficient for each analyzed variable. For each new test, the new CV value is determined. When the value no longer increases or when it shows a negligible change, the number of dynamometric tests is established as being adequate for each response variable.

RESULTS AND DISCUSSION

The atmospheric conditions during data collection were as follows: The air temperature went from 22 °C to 27 °C, the relative humidity of the air decreased from 65% to 53%, and the atmospheric pressure remained unchanged at 100.3 kPa. In aspirated engines, air pressure directly affects the power, as it depends on the amount of oxygen that can be burned (BRUNETTI, 2012). Turbocharged engines; however, react differently to these factors, as is the case with the engine used in this experiment. Atmospheric pressure variations cause little or no change in the result for these engines (MÁRQUEZ, 2012).

It is important to note that the correlation between hourly and specific fuel consumption is 100%, given that its determination is based on hourly consumption. The non-significant correlation between hourly consumption and engine power was 86%, showing that the greater the power generated, the greater the fuel consumption (Table 2).

The linear correlation between hourly consumption and torque was 19%, demonstrating that the correlation is low and non-significant, and there is no way to use hourly fuel consumption to relate it to the engine torque. The linear correlation between torque and power, also non-significant, was -60%. Power is calculated from the engine's torque and angular speed, and while the power tends to increase, the torque tends to decrease within the engine's utilization range, which explains this negative linear correlation value.

The variation in torque, power and fuel consumption, considering the warming-up time, is shown in figure 1. The behavior of the engine performance characteristic curves was not affected by the warming-up time, especially when the torque and power variables are analyzed.

A difference in both hourly and specific consumption can be observed, with fuel consumption being lower for the 20-min warm-up time, greater for the 60-min warm-up time, and; subsequently, decreasing again with the100-min warm-up time (Figure 1).

The results of the analysis of variance (ANOVA) indicate that the warm-up time did not influence the results of any of the performance parameters analyzed. This means that it is not necessary to warm up the tractor engine for a period longer than 20 min to start collecting data.

Considering that the warm-up time had no influence on the parameters evaluated, the determination of the number of dynamometric tests took into account the 18 tests in only one group. The dispersion of the response variables for each analyzed parameter and for each engine's angular speed (18 points per angular speed) is presented in figure 2, represented by a boxplot or box diagram.

In figure 2, it can be observed that the dispersion of torque and power data has less variation in observations than the hourly and specific fuel consumption readings. This is because the methods and instruments for collecting data on an hourly consumption basis are less accurate in relation to data collection using the dynamometric brake.

Another point to highlight about data collection by the dynamometer is that the first collection, corresponding to the angular speed of 2350 rpm, is the one with the greatest data dispersion, because at this point, the dynamometer needs to stabilize its parameters in order to start the readings. However, in the range of angular speed comprised between the maximum power (at 2250 rpm) and the maximum torque (at 1550 rpm), considered as the range of use of the engine, the dispersion of the test results is smaller.

This is important, since it is in this range of engine angular speed that the tractor will work during agricultural operations, coinciding with the highest reliability of the analyzed data. Working in the medium range of torque and angular speed allows the engines to run in ideal conditions, providing good results for field operations and satisfactory results, in terms of fuel consumption and pollutant emissions (LOVARELLI & BACENETTI, 2019).

Once the dispersion analysis of the observed data was performed for each angular speed, another analysis was carried out to determine the ideal number of tests, taking into account the smallest CV between the tests. Figure 3 shows that the lowest CV occurred in the first four tests performed, both for the torque and the power variables. As for hourly and specific fuel consumption, the lowest CV occurred with 17 tests. However, the statistical advantage of

Table 2 - Linear correlation between the analyzed engine performance parameters.

	Torque	Power	Hourly fuel consumption	Specific fuel consumption
Torque	1.00	-0.60	0.19	0.19
Power	-0.60	1.00	0.86	0.86
Hourly fuel consumption	0.19	0.86	1.00	1.00
Specific fuel consumption	0.19	0.86	1.00	1.00

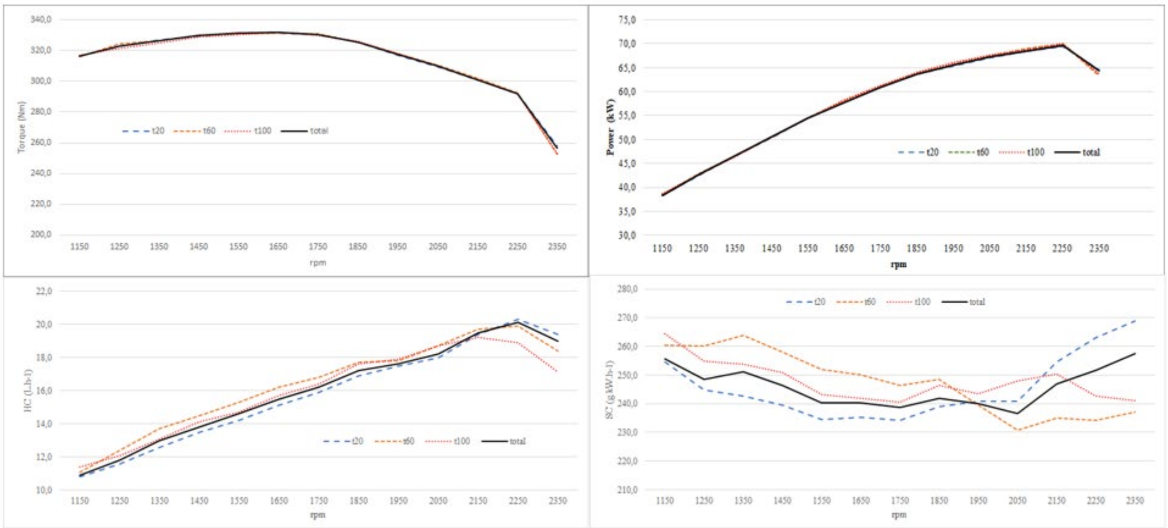

Figure 1 - Variation of engine performance parameters considering the warm-up time.

decreasing the CV from 4.5% to 4.0% does not justify performing 17 dynamometric tests.

It should be noted that the CV was approximately 10 times greater for consumption variables than for torque and power (Figure 3). This can be explained by the less dispersed nature of the data collected in each of the tests (Figure 2), and it depends on the accuracy of each reading instrument.

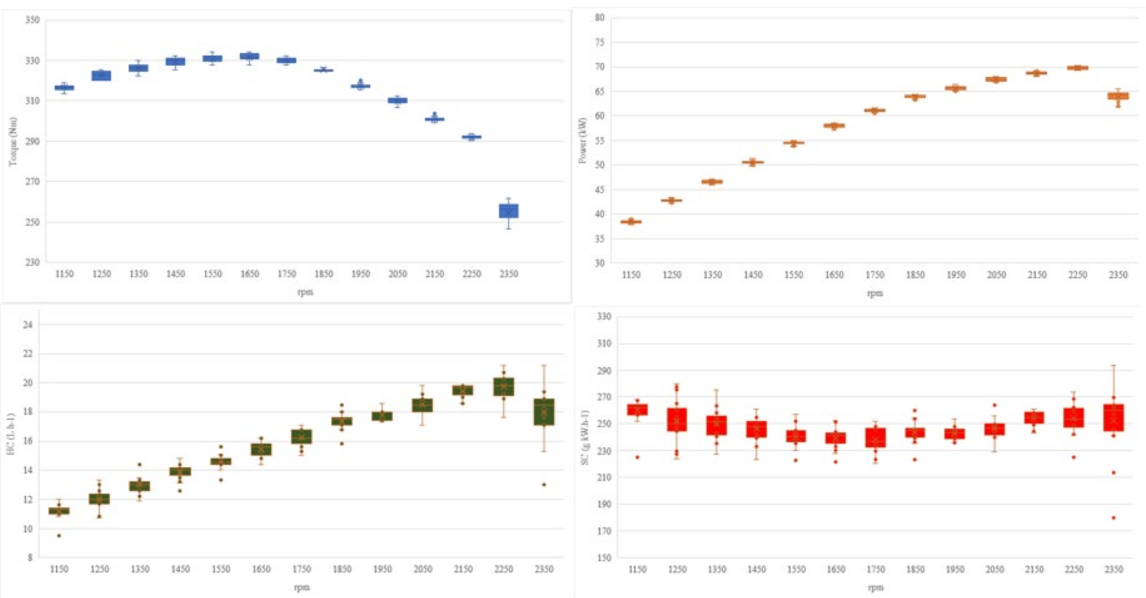

Figure 2 - Boxplot of medians and quartiles for engine performance parameters considering the 18 repetitions.

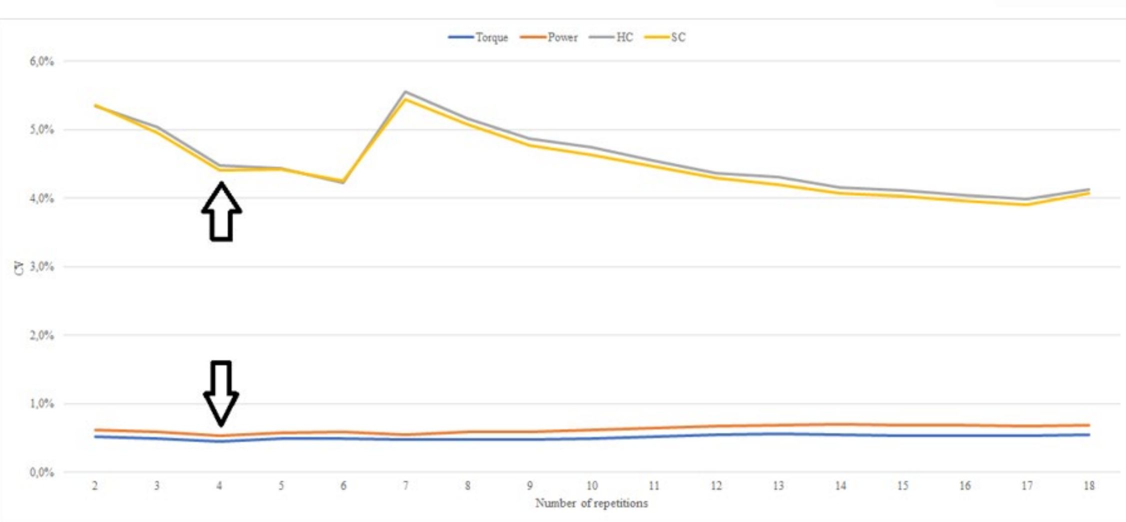

Figure 3 - Behavior of the coefficient of variation (CV) as a function of the number of repetitions, for the engine performance parameters.

CONCLUSION

To carry out a dynamometric test, the Diesel cycle engine warm-up time required to stabilize the performance parameters is 20 min.

Four tests are sufficient to evaluate the engine's torque, power, and hourly and specific fuel consumption parameters needed to reduce the experimental error.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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AUTHOR'S CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript.

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