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RURAL ENGINEERING

Performance of an agricultural engine using mineral diesel and ethanol fuels

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ABSTRACT: *The global demand for alternatives for mineral diesel oil is growing due to the need for satisfying sustainability and environmental requirements, forcing industries and research institutions to develop new alternative fuels. The objective of this study was to evaluate the performance parameters of an agricultural engine using two different fuels: mineral diesel oil and ethanol. The experiment was conducted on a dynamometric stand using two engines for agricultural use but with a modified fuel injection system, suitable for both diesel and ethanol, in the speed range 1200-2300rpm. The performance of the engines was analyzed considering the power take-off from the tractors for each fuel, as established in the standard NBR ISO 1585. The data obtained showed that at the working speed that provides 540rpm at the power take-off, the engine performance changed when powered by ethanol, with a reduction in the maximum power and increased specific fuel consumption.*
Key words: *alternative fuels, diesel cycle, agricultural tractor, brake dynamometer.*

Desempenho de um motor agrícola utilizando Diesel mineral e etanol

RESUMO: *A demanda mundial por combustíveis alternativos ao óleo Diesel mineral vem crescendo, tanto pela sustentabilidade, quanto por exigências ambientais. Isso faz com que as indústrias e as instituições de pesquisa desenvolvam novas alternativas para o uso destes combustíveis. Nesse contexto, objetivou-se avaliar os parâmetros de desempenho de um motor agrícola, com dois diferentes combustíveis, Diesel mineral e etanol. O experimento foi realizado em bancada dinamométrica, utilizando dois motores de uso agrícola, porém, com alterações no sistema de injeção de combustível, Diesel e etanol, na faixa de rotação entre 1200 e 2300rpm. O desempenho dos motores foi analisado por meio da tomada de potência dos tratores para cada combustível, conforme estabelece a norma NBR ISO 1585. A partir dos dados obtidos, concluiu-se que, ao considerar a rotação de trabalho que fornece 540rpm na tomada de potência, houve alteração no desempenho do motor movido a etanol, com redução da potência máxima e aumento do consumo específico de combustível.*
Palavras-chave: *combustíveis alternativos, ciclo Diesel, trator agrícola, freio dinamométrico.*

INTRODUCTION

Efforts to minimize the use of mineral diesel oil and, thus, the emission of pollutants into the atmosphere are being made in many countries by replacing mineral diesel or by adding renewable fuels to the blend (MAULE et al., 2001). GRANDO (2005) proved the benefits of green fuels (biofuels), and showed that similar to biodiesel, ethanol can also contribute to improving environmental conditions by reducing gas emissions.

In Brazil, the use of biomass as an alternative fuel to reduce the dependency on fossil fuels and greenhouse gas emissions has been known for decades. In the industry, engine manufacturers from different sectors have already mastered the use of biodiesel in diesel cycle engines, allowing its complete or partial use as fuel.

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Some studies showed that there are differences in engine performance parameters when other fuels are used to replace mineral diesel partially or fully. By studying blends with increasing amounts of biodiesel added to mineral diesel, SALA (2008), NIETIEDT et al., (2011), and FIORESE et al. (2012) obtained similar engine performance results with regard to torque, power, and specific fuel consumption.

In the automotive industry, ethanol has been used in Otto cycle engines; the use of ethanol has led to the development of the so called "flex" technology that allowed operation with 100% gasoline or ethanol as fuel. In the agricultural machinery industry, such technology has not been used, but in the recent years, some companies have gained interest in the subject and have directed their efforts to the use of these engines in agricultural tractors. However, the results in the form of industrial products are still unknown. Many countries have established national goals with regard to biofuels and provided incentives and support to accelerate the growth of the bioenergy industry (YUE et al., 2014).

Considering the strong dependency on fossil fuels, liquid fuels derived from biomass and products that are energy sources are proposed as a part of the solution to climate change. This is because the raw material composed of renewable biomass can be produced from a variety of sources, and the production and use of bioenergy and biofuels have potentially low environmental impacts as compared to oil products (MARQUARDT et al., 2010; AN et al., 2011; GOLD & SEURING, 2011).

In general, ethanol powered engines were introduced in the field of agriculture in the sugar alcohol sector due to the availability and low cost of this fuel. The agricultural tractor is the most employed machine among rural properties, with approximately 29 million tractors being used in the world (BILSKI, 2013). Its use is highly diversified, and the need for optimizing its performance is an important research problem (VALE et al., 2011).

For selecting the ideal tractor for agricultural operations, different factors such as power, comfort, maneuverability, maintainability, and purchasing price are considered; in addition, knowledge of tractor's energy efficiency can be considered during selection (SILVEIRA & SIERRA, 2010).

Based on the dynamometric trials by the power take-off (PTO), engine performance parameters such as torque, effective power, and specific fuel consumption can be obtained under certain engine operating conditions, which refer to the percentage of power and engine speed in relation to the nominal power (SILVEIRA et al., 2008). Dynamometric brakes, which are usually electric, are used to evaluate performance, as reported by ALVAREZ & HUET (2008) based on their studies on the assessment of tractors in extension projects in France.

Because of the need for additional information on the use of fuel alcohol as an energy source for tractor engines, the primary objective of this study was to evaluate the performance parameters of an agricultural engine with two different fuels: mineral diesel and ethanol.

MATERIALS AND METHODS

The data were collected by performing dynamometric tests using two engines for the same John Deere agricultural tractor (model 6415), equipped with used John Deere diesel cycle engine (model 4045T, series 350), turbocharged with direct injection four cylinder and 4.5L of displaced volume. The rated power level was 78kW (106cv) at 2300rpm, and the maximum torque was 423Nm at 1500rpm, when operating with mineral diesel.

Tractor's original fuel injection system for mineral diesel operates with a Delphi rotary injection pump (model DP100). To activate the ethanol powered tractor engine, the fuel injection system was modified by replacing the injector nozzles for spark plugs and the rotary injection pump for an electronic module responsible for injection and ignition control, to ensure that the engine would function optimally. The volumetric compression ratio of the engine adapted for the use of ethanol was not changed. Diesel oil filters, piping, and other specific components were modified to work with ethanol.

Mineral diesel used in the experiment had the following physicochemical properties: 500ppm of sulfur (S500), 5% biodiesel (B5), a lower calorific value of 10,095kcalkg^{-1}, a density of 0.835kgL^{-1} at a room temperature of 20°C, and a cetane number of 50.3. The ethanol presented 4.8% of water content in relation to the total volume, a lower calorific value of 6,300kcalkg^{-1}, and a density of 0.808kgL^{-1} at 20ºC.

The values for the torque and effective power were obtained by using electric parasitic current (Foucault currents) dynamometric brakes (brand MWD, model NL 480). These brakes can be used by tractors with up to 552kW (750cv) of continuous maximum power, a maximum speed of 3,600rpm, and a maximum torque of 2,942Nm.

To measure fuel consumption, the volumetric method was applied, by disconnecting the original fuel supply system and connecting it to a 2L container marked with a 25mL scale. When the engine speed was maintained according to the exerted load, the time taken by the engine to consume a known volume was measured, thus obtaining the volume consumed in liters per hour (Lh^{-1}) for the two fuels.

To perform the experiment, the dynamometric brakes were coupled to the PTO of the tractor. The data were acquired manually, using the software program Accudyno®. The experiment was conducted as per the procedures prescribed in the standard NBR ISO 1585by the Associação Brasileira de Normas Técnicas (ABNT, 1996); this standard is applied to the performance assessment of internal combustion engines. The curves for torque, power, and specific fuel consumption at full charge, in particular, according to engine speed were obtained.

First, prior to the evaluations, the tractor's fuel supply system was drained and disconnected from the tank. Then, it was connected to an external supply container containing diesel and ethanol and thus acted as the energy source of the supply system. When the fuel was replaced, the container was washed to prevent contamination and mixing of fuels.

The engine configuration used with diesel fuel was the standard one provided by the manufacturer. When using ethanol, tests were performed to identify the configuration that provided the best yield. Various previous tests were performed to find the maximum performance condition of the ethanol injection system.

At the beginning of the investigation, the tractor engine was set to the maximum speed for both fuels, and the dynamometer was programmed to offer partial charges through the software. The settings allowed acquiring data on the variables, namely, torque and effective power, with decrease in speed every 100rpm. Fuel consumption according to engine speed was obtained indirectly.

A completely randomized experiment design (CRD) was applied, with 12 treatments (engine speeds), in the range 1200-2300rpm, in triplicate. Data obtained for each fuel studied here was subjected to analysis of variance (ANOVA) at a 5% significance level, and the means were adjusted by using regression equations with the assistance of the software program Sisvar version 5.3 (FERREIRA, 2011).

RESULTS AND DISCUSSION

ANOVA of the results for torque, effective power, and specific fuel consumption for the evaluated engine speeds (treatments) for both fuels (Table 1), showed that all the parameters presented significant variation. To facilitate visualization and analysis of results, the data were presented in graphs, and the trend lines for the evaluated parameters were plotted.

As shown in figure 1A, when mineral diesel was used, the curve for power was greater than that for ethanol, and the difference between the maximum powers obtained with the two fuels was 49.76%. The greatest difference (71.68%) was observed at a speed of 2300rpm. During the experiment, the maximum power achieved by the engine fueled by mineral diesel was 69.70kW (94.80cv) at 2000rpm.

The ethanol-powered tractor had lower performance at all the speeds studied. The maximum power was 35.0kW (47.60cv) at 1600rpm. Beyond this speed, the power curve for this engine did not follow the characteristics of the standard power curves for diesel cycle engines (Figure 1C).

Table 1 - Summary of ANOVA for the parameters: torque (Nm), effective power (kW), and specific fuel consumption ($gkWh^{-1}$).

Fuel	Sources of variation	Degrees of freedom	----------Mean squares----------		
			Torque	Effective power	Specific fuel consumption
Mineral diesel	Engine speed*	11	6365.50	118.93	1880.78
	Error	24	23.36	0.85	8.96
	CV (%)	-	1.34	1.43	1.17
	Overall mean	-	361.27	64.67	255.46
Ethanol	Engine speed*	11	12652.21	113.21	246950.93
	Error	24	88.08	4.66	12273.82
	CV (%)	-	5.51	7.45	14.73
	Overall mean	-	170.33	28.98	752.15

*There was a significant effect ($P \leq 0.05$).

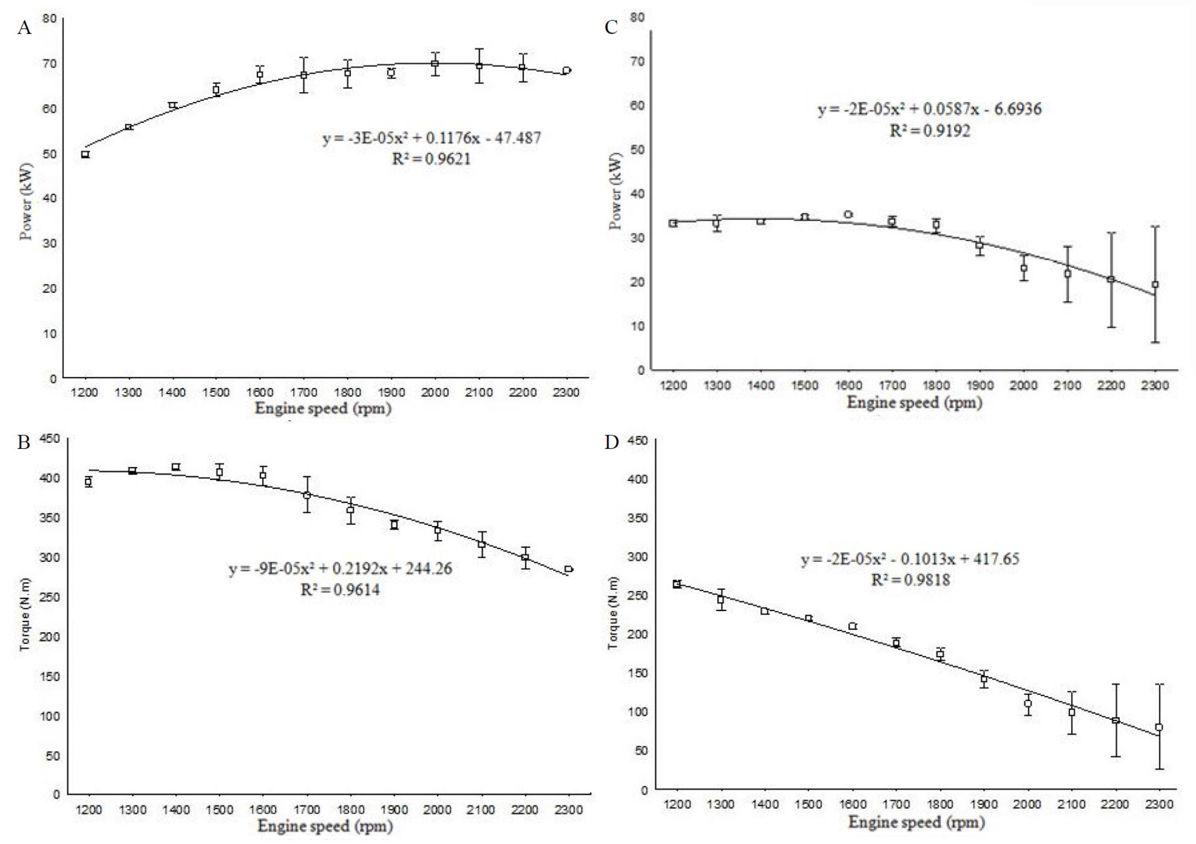

Figure 1 - Power and torque performance for the engine using mineral diesel (A and B) and ethanol (C and D) in the speed range studied.

NIETIEDT et al. (2011) observed similar behavior with a decrease in the values of power when 100% biodiesel was used, with regard to mineral diesel (B5), at corresponding engine speeds.

With regard to the torque performance parameter, a similar behavior as in the power curves was seen in figure 1B and 1D, with the mineral diesel powered engine yielding better results. The maximum torque obtained by this engine when running on diesel was 413.50Nm at 1400rpm, while the ethanol powered engine achieved a maximum torque of 264Nm at 1200rpm; thus, the maximum values differed by 36.16%. BARBOSA et al. (2008) obtained similar results when using biodiesel as fuel; and when 100% biodiesel was used, the torque and power values for the different speeds tested were less than the corresponding values for mineral diesel.

Based on the torque and speed values, two attributes for evaluating engine performance were determined: torque rise and range of use. Mean values obtained for torque rise of the mineral diesel and ethanol powered engines were 24.16% and 26.28%, respectively. MÁRQUEZ (2005) established four torque rise categories: low - for engines whose torque rise ranged 10 to 15%, average - for values between 15 and 25%, high - for values from 25 to 35%, and very high - for values exceeding 35%. Range of use for the ethanol powered engine was 400rpm, and that for the mineral diesel powered engine was 600rpm. In general, the torque rise and range of use of a multi task tractor should be higher than 20% and at 800rpm, respectively (MÁRQUEZ, 2005).

According to PENIDO FILHO (1981), the major problem in using ethanol in engines originally developed for diesel is the adjustment of the compression ratio, which is higher for diesel and cannot be optimized to operate with ethanol, which generates disadvantages such as lower power, lower torque, and higher consumption, are observed when using ethanol with such engines, as reported in this study.

Figures 2A and 2B present the behavior of the specific fuel consumption, highlighting the lower values for the engine operating with mineral diesel. Analysis of results for specific consumption

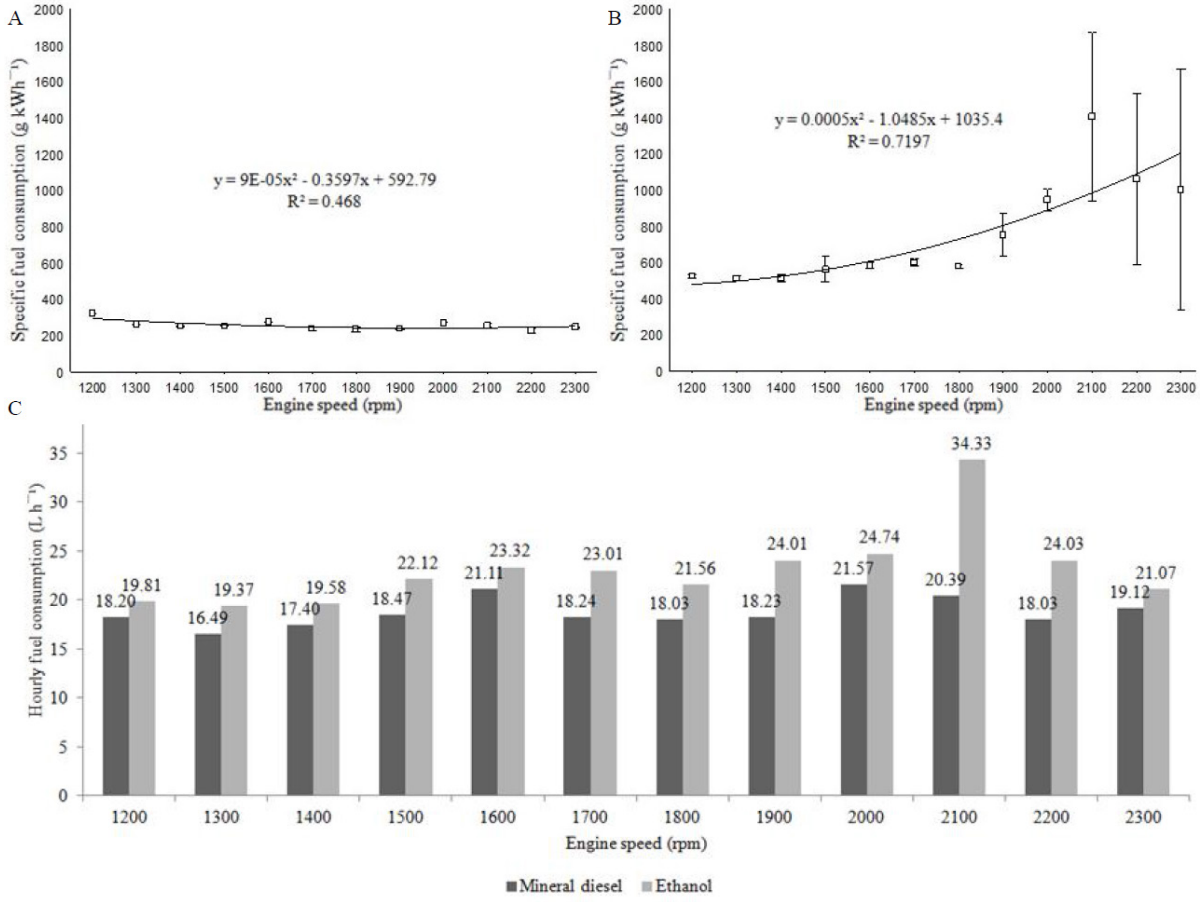

Figure 2 - Specific fuel consumption curves for mineral diesel (A) and ethanol (B); and hourly fuel consumption (C) for both.

using the engine speed of 2100rpm, which provides 540rpm at the PTO as a basis indicated that the use of mineral diesel to a lower mean value on the order of 257.30gkWh^{-1}. At the same speed, the consumption was high for ethanol (1404.06gkWh^{-1}).

With regard to hourly fuel consumption, the average consumption values at the operating speed (540rpm at the PTO) for the diesel and ethanol engines were 20.39Lh^{-1} and 34.33Lh^{-1}, respectively. The greatest difference (68.37%) between the tested fuels in terms of the fuel consumption occurred at this speed, which corresponds to 2100rpm of the engine (Figure 2C).

The comparison of the mean results of the three evaluated performance parameters indicated that the engine powered by mineral diesel had the best performance. When using this fuel, the engine achieved torque and effective power values that were 52.85% and 55.19% higher, respectively, and specific fuel consumption that was 194.43% lower than those for the ethanol powered engine.

CONCLUSION

Considering the working speed, which provided 540rpm at the PTO, performance of the engine changed when using ethanol as an energy source. The maximum power decreased, and the specific fuel consumption increased.

The low performance of the ethanol powered engine is attributed to the lack of modifications to its structure, particularly regarding the compression rate and adjustment of the fuel injection system.

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