ORIGINAL ARTICLE

Study of the parameters of the MWM International engine when using Jatropha curcas diesel-biodiesel mixtures

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Estudio de los parámetros del motor MWM Internacional al emplear mezclas diésel-biodiesel de *Jatropha curcas*

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ABSTRACT: The depletion of fossil fuels is eminent over time due to its non-renewable nature. The use of biodiesel is a viable option to stop its decline since it is obtained from biomass. Due to the importance of the percentage of biodiesel that can be added without affecting the operation of the MWM International model 6.10T engine coupled to a Worthington vertical deep well pump. This research was developed in the Department of Engineering and Environment, of the Institute of Animal Science. The pumping system used in the water supply for the institute and the community was evaluated. Biodiesel-diesel blends (B-0, B-5, B-10, B-15, B-20, B-25 and B-30) were handled with three rotation frequencies (1350, 1550, 1750 min^{-1}). The hourly consumption (Gh) did not show statistically significant differences in the rotation frequencies 1350 and 1550 min^{-1}, only at 1750 min^{-1} the highest consumption is obtained when using 30% biodiesel. The specific fuel consumption (ge) at 1750 min^{-1} showed statistically significant differences only in B-30 and at 1350 min^{-1} the highest consumption was observed in B-5 and B-30. When the engine is running for 1000 hours of work, the B-20 and B-25 blends obtain the most economically efficient values, with 9 780 and 9 070 pesos, respectively. By studying all the blends analyzed, it can be stated that B-20 and B-25 are the most recommended to use.

Keywords: Fossil Fuel, Operation, Economic Efficiency, Variance Analysis.

RESUMEN: El agotamiento de los combustibles fósiles es eminente en el transcurso del tiempo por su carácter no renovable. El uso de biodiesel es una opción viable para frenar su disminución ya que su obtención proviene de la biomasa. Por la importancia que reviste el tema, se requiere determinar el porcentaje de biodiesel que se puede añadir sin afectar el funcionamiento del motor MWM Internacional modelo 6.10T acoplado a una bomba vertical de pozo profundo marca Worthington. La presente investigación se desarrolló en el departamento de Ingeniería y Medio Ambiente, del Instituto de Ciencia Animal. Se evaluó el sistema de bombeo que se usa en el abastecimiento del agua para el instituto y la comunidad. Se manejaron mezclas diésel-biodiesel (B-0, B-5, B-10, B-15, B-20, B-25 y B-30) con tres frecuencias de rotación (1350, 1550, 1750). El consumo horario (Gh) no evidenció diferencias estadísticamente significativas en las frecuencias de rotación 1350 y 1550 min^{-1}, solo en 1750 min^{-1} se obtiene el consumo más elevado al utilizar el 30% de biodiesel. El consumo específico de combustible (ge) a 1750 min^{-1} demostró diferencias estadísticamente significativas solo en B-30 y en 1350 min^{-1} el mayor consumo se observó en B-5 y B-30. Al estar el motor en funcionamiento durante 1 000 h de trabajo, las mezclas B-20 y B-25 obtienen los mejores valores con respecto a la eficiencia económica, con 9 780 y 9 070 peso, respectivamente. Al estudiar todas las mezclas analizadas se puede afirmar que B-20 y B-25 son las más recomendables para utilizar.

Palabras clave: combustible fósil, funcionamiento, eficiencia económica, análisis de varianza.

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INTRODUCTION

The agricultural sector carries out daily activities that pollute the environment, mainly because the machinery used expels greenhouse gases. Likewise, another challenge faced is that the fuel used is non-renewable. The imminent climate change and the effects on nature require the search for viable energy sources. Vieira (2020) states that the increase in energy consumption and the imminent depletion of fossil fuels has encouraged countries to seek innovative and clean energy sources.

Biomass does not require a formation process of thousands of years as is the case with fossil fuel, which is why it is considered a renewable energy. It can be used directly by burning firewood or by transforming it to produce biofuel. However, it must be taken into account that the indiscriminate use of this resource has a negative impact on the agricultural sector. The largest productions are made with agricultural materials (corn, soybeans, sugar cane, African palm, etc.), directly affecting food security (Gonzales et al., 2017). For this reason, there are many divergent criteria regarding whether obtaining biofuels provides protection of the rights of nature.

Many authors (Trejo, 2007; López and De los Santos, 2012; Rey, 2014) agree that obtaining them affects the ecological and environmental system, in addition to putting rights such as food at risk due to the use of large areas of land and the raw material used for its production. On the other hand, we can cite (Ramos et al., 2016 and Gonzales et al., 2017) who propose that the approach to not have a negative impact on the environment must be directed to the production method and the material from which are obtained. For greater sustainable or sustainable development, the most viable option is second generation biofuel (G2). It is because they can be acquired from crops grown in marginal and unproductive areas not intended for food, which require little water and fertilizer. In addition, environmentally friendly and mostly economical technologies are used. Its manufacturing depends largely on the national availability of energy crops (Díaz and Pérez, 2021).

Currently, Cuba needs to reduce imports and increase the energy sector with clean and renewable energy. The 2030 Agenda allows the focus as individuals, state and institutions on the development of sustainability. The National Economic and Social Development Plan until 2030 states that the Government will promote energy efficiency and the development of renewable energy sources, promoting their participation in the national energy matrix, with emphasis on biomass, wind and photovoltaics (Verdejo et al., 2020).

In the case of biomass, specifically the production of biodiesel, progress is being made towards the generalization of the technology and its greatest production in Cuba is obtained from Jatropha curcas (Piloto, 2021). This plant is known in tropical and semi-tropical countries for its potential for obtaining this biofuel. Its resistance to drought, high oil content, adaptation to different conditions and rapid growth characterize it. In sandy soils, they can reach heights of 1 to 8 m (Bárzaga et al., 2015).

The use of diesel-biodiesel mixtures is the worldwide solution to the use of fossil fuel in machinery. By using them, it is possible to reduce dependence on petroleum derivatives and reduce polluting gases. Researchers such as (García et al., 2018, Piloto et al., 2018), propose that the biodiesel obtained from Jatropha curcas can be used in **ICMs**, because it presents similarities in the viscosity and density properties with the diesel which are the main characteristics to take into account. However, these differences in properties have an impact on the engine parameters, such as viscosity, which has a direct influence on the fuel injection and atomization process (Riba et al., 2010).

For all the reasons stated above, it is necessary to determine the percentage of biodiesel that can be added without affecting the operation of the MWM International engine coupled to a Worthington brand deep well vertical pump. In addition, know the operation of the engine parameters, as well as the economic behavior of the mixtures when using this fuel.

MATERIALS AND METHODS

The experiment was carried out in the Department of Engineering and Environment, of the Institute of Animal Science (ICA). The pumping system used to supply water to the institute and the community was evaluated. Three pumpings are carried out a day; the tank is mushroom-shaped with a volume of 283.91 m^3. The engine used is an International MWM; model 6.10T and a Worthington brand vertical deep well pump. The head is Italian, Roto Pompe brand with a maximum rotation frequency of 1760 min^{-1} and a capacity of 5.5 L.

Through the “Indio Hatuey” Experimental Station (EEPF-IH) and LABIOFAM in Guantánamo, it was possible to obtain the Jatropha curcas biodiesel that was used in the experiment, while the diesel used came from the ICA supply track. The first step was to define the percentage to add to the mixture (0%; 5%; 10%; 15%; 20%; 25% and 30% biodiesel) and identify the rotation frequency to work (1350, 1550, 1750 min^{-1}). To measure the test time, a digital stopwatch is used, with a precision of ± 0.01s, and the digital tachometer is used to identify the rotating frequency.

To calculate the engine parameters, the following expressions were used:

$$ge = \frac{Gh}{Ne}\ , \qquad \frac{L}{kW.h} \quad (1)$$

$$Gh = \frac{Gc}{t}\ , \qquad \frac{L}{h} \quad (2)$$

Where:
Pbe: braking effort, N;
kgf; ß: distance, m;
Gc: fuel consumption, L;
t: time in which the supplied fuel is consumed, h.

The experiment engine is not used on a test bench. Instead, it is coupled to a hydraulic pump, so some modifications are made to the methodology for calculating Ne and Me.

From what is stated above, we have the following mathematical expressions:

$$Ne = Nh{*}\eta h \quad (3)$$

$$Me = \frac{Ne{*}9\,550}{n}\ ,\ kW \quad (4)$$

$$Nh = Q{*}h{*}\rho{*}g \quad (5)$$

By multiplying ρ*g we obtain γ, so the equation becomes:

$$Nh = Q{*}h{*}\gamma \quad (6)$$

$$Nh = Q{*}h{*}9{,}81 \quad (7)$$

Where:
ρ: is the density of the fluid (1,000 kg/m³ in the case of water);
g: is the acceleration of gravity (generally adopted: 9.81 m/s2);
γ: is the specific weight of the fluid
Q: is the flow rate, m³/s;
h: is the head gain in the pump, or in other terms, dynamic head of the pump, m.
Where:
k: resistance coefficient per accessory
v: fluid velocity in the pipe, m^2/s;
g: acceleration of gravity, m/s^2.

In the economic analysis, the cost of the fuel consumed is fundamentally considered. It is determined based on the hourly fuel consumption (Gh) during the experiment period, with respect to its price (EP PETROECUADOR., 2020). For the determination, the expression is used:

$$Cc = Gh \cdot Pc,\quad peso/h \quad (8)$$

Where:
Gh: Hourly fuel consumption, L/h;
Pc: Fuel price, weight/L

RESULT AND DISCUSSION

From the data collected, it was possible to obtain the following engine parameters: hourly consumption (Gh), specific fuel consumption (ge), effective power (Ne) and the torque (Mt) of the engine when coupled to a pump of the water. An analysis of variance was performed on the results of the Gh and ge according to a simple Classification model with factorial arrangement 7 (mixtures) x 3 (min^{-1}) Duncan. (1995) . Where Duncan's test was applied for P<0.05 and the statistical package used was Infostat Di Rienzo et al., (2012). In addition, an economic feasibility analysis is carried out based on Gh when working at 1750 min^{-1}. The following Table 1, shows the statistical analysis of hourly consumption at frequencies 1350, 1550 and 1750 min^{-1}.

TABLE 1. Statistical analysis of the hourly consumption

Indicator	Mixtures B/min^{-1}	1750	1550	1350	EE± y sign
Hourly consumption (Gh), [L/h]	0	19,34[cd]	14,02[b]	10,43[a]	0,38 P=0,0427
	5	19,16[cd]	14,06[b]	11,60[a]	
	10	19,25[cd]	14,16[b]	10,90[a]	
	15	19,97[d]	13,68[b]	10,93[a]	
	20	19,33[cd]	13,77[b]	10,93[a]	
	25	18,44[c]	13,48[b]	10,58[a]	
	30	21,47[e]	14,02[b]	11,24[a]	

a,b,c,d,e: different letters; They differ at P<0.05.
EE: standard error sign: significance

When analyzing the evaluated mixtures, it is evident that the rotation frequencies 1550 min^{-1} and 1350 min^{-1} do not present statistically significant differences between them. This result is due to the low power at which the motor is working with respect to its rotation frequency. In the case of 1750 min^{-1}, statistically significant differences are evident between the diesel-biodiesel concentrations, where an increase in consumption is evident compared to 1550 and 1350. If each of the mixtures is observed at 1750 min^{-1}, it can be concluded that the Greater fuel consumption is in B-30 due to the lower calorific value of the fuel used. This is due to the engine's need to consume more fuel to achieve the same power. Dinza et al., (2020) agree with this result, since they express that Gh increases with the increase in engine loads because vegetable oils and therefore their mixtures with traditional fuels have lower caloric value than conventional diesel.

The following Table 2, shows the statistical analysis of the specific fuel consumption at frequencies 1350, 1550 and 1750 min^{-1}. These results show that at 1550 min^{-1} there are no statistically significant differences. On the other hand, at 1750 min^{-1} there are only differences in the B-30 mixture, which is due to the greater hourly consumption of the engine and the lower calorific value of the fuel. Similar results have been reported by Piloto et al. (2013) where the increase in biodiesel content in the mixture is evident, by increasing the specific fuel consumption, (García et al., 2019) coincides with these results.

Regarding the frequency of 1350 min^{-1} of the mixtures, it shows that there are no statistically significant differences; only in the case of B-5 and B-30 are the highest values of specific fuel consumption reached.

TABLE 2. Statistical analysis of the specific fuel consumption

Indicator	Mixtures B/min^{-1}	1750	1550	1350	EE± y sign
Specific fuel consumption (ge), [L/kW*h]	0	0,308^{abcd}	0,332^{ef}	0,366^{g}	0,006 P=0,0051
	5	0,305^{abc}	0,333^{ef}	0,407^{i}	
	10	0,306^{abc}	0,335^{ef}	0,382^{gh}	
	15	0,301^{ab}	0,324^{cdef}	0,384^{gh}	
	20	0,306^{abc}	0,326^{def}	0,384^{gh}	
	25	0,294^{a}	0,319^{bcde}	0,371^{g}	
	30	0,342^{f}	0,332^{ef}	0,395^{hi}	

a,b,c,d,e: different letters; They differ at P<0,05. EE: standard error, sign: significance

The non-existence of significant differences in most of the values presented in the table is due to the better combustion of the mixture and engine efficiency. The recoil of the fuel and the turbocharger that the MCI presents causes this.

Regarding the engine power and the torque, three values were obtained respectively for each of the rotation frequencies. The data is represented in graphs for better analysis. In the Figure 1 shows the values obtained based on the three rotation frequencies (1350, 1550 and 1750 min^{-1}).

When analyzing the values, a decrease in the parameters is seen at the lower motor frequencies. This is because it is being underused since its nominal rotation frequency is 2,600 min^{-1}; however, it was worked with lower frequencies. The use of lower revolutions depends on the fact that the pump to which the motor is coupled has a head that only supports up to 1770 maximum rpm. Regarding the torsional moment, their results are similar due to the exceptional conditions under which they worked.

Table 3, shows the price of fuel from 2015 to 2020. After obtaining the Gh of all the mixtures, the economic feasibility analysis is carried out using expression 1. The hourly consumption values used are at 1750 min^{-1}. Since the rotation, frequency is closest to the nominal of the motor.

TABLE 3. Diesel fuel prices per year, USD

Year	Price (USD)/Gal	Price(USD)/L
2015	1,67	0,44
2016	1,37	0,36
2017	1,69	0,45
2018	2,11	0,56
2019	1,96	0,51
2020	1,18	0,31

Source: EP PETROECUADOR, 2020. Organized by the authors

The following Table 4, shows the economic feasibility analysis of the fuel mixtures in the years 2018, 2019 and 2020. In addition, the cost of fuel consumed in the engine after 1,000 hours of operation can be seen with respect to the price of diesel in 2018.

When analyzing the data presented above, it can be observed that the lowest fuel consumption expense is obtained in the year 2020. REN21 (2020) reports that this is a year in which fuel consumption decreased and therefore its price caused by the special situation experienced with the pandemic (COVID-19). The B-25 mixture is where the lowest values of consumption expenditure are reached in the three years analyzed; it is due to the increase in the percentage of biodiesel in the mixture without

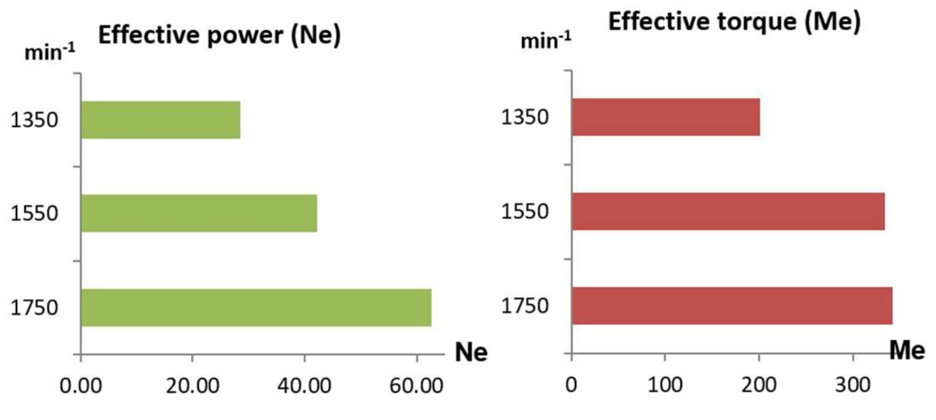

FIGURE 1. Behavior of effective power and effective torque of the motor as a function of the three rotation frequencies.

TABLE 4. Cost of fuel consumption in the years 2018, 2019 and 2020

Mixtures	Cost of fuel consumption, peso/h (2018)	Cost of fuel consumption, peso/h (2019)	Cost of fuel consumption, pesot/h (2020)	Cost per 1000 hours of operation, peso (2018)
B-0	10,83	9,86	6.00	10 830
B-5	10,46	9,55	5,91	10 460
B-10	10,25	9,39	5,92	10 250
B-15	10,37	9,51	6,12	10 370
B-20	9,78	9,01	5,91	9 780
B-25	9,07	8,38	5,61	9 070
B-30	10,28	9,52	6,51	10 280

presenting significant differences in Gh. B-20 prices are also satisfactory when compared to pure diesel. Therefore, it can be concluded that there is a decrease in fuel consumption expenditure by increasing the percentage of biodiesel in the mixture. In the case of B-30, an increase is evident in all years since it has the highest hourly consumption.

By analyzing all the values of the studies carried out, it can be concluded that mixtures B-20 and B-25 are the most suitable to use without affecting the engine, due to their similar behavior with respect to B-0. However, it is necessary to point out that it is vitally important to know the behavior of the greenhouse gases that are expelled into the atmosphere through combustion; this is because these mixtures would not necessarily be the most suitable if the environmental component is analyzed. The polluting gases expelled into the atmosphere are harmful to the environment and human health. Its reduction makes it possible to counteract the climate change that is currently causing so much damage in the world. In addition, it is necessary to know the durability of the engine parts when using this specific biodiesel, which has lower calorific value and different viscosity and density properties than pure diesel.

CONCLUSIONS

- The cost per fuel expenditure is reported when the engine is in operation for 1,000 hours of work, where it is evident that B-20 and B-25 obtain the most efficient values, with 9,780 and 9,070 pesos, respectively.
- The use of diesel-biodiesel mixtures in an MWM International engine allows us to reduce dependence on traditional fuels and imports.
- In this work it is possible to identify the most suitable mixtures (B-20 and B-25) to be used in an International MWM engine coupled to a Worthington brand deep well vertical pump without making modifications.

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