TESTS OF DIFFERENTIAL DIESEL FUELS IN ENGINE TESTING ROOM

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Abstract: The portion of oil could be estimated 33 % of global primary energy consumption in 2012 (BP, 2012) and its average price – beside the products produced from it as well - significantly increased, unlike the demand for transport which has been reduced. This tendency is expected to remain unchanged in the long run, therefore, there is a great importance for the variety of diesel fuel distributors, in comparison of the ratio value for each of them, and replacing them with biodiesel can be used in the comparison. We executed 3 dynamometer measurements performed to determine three different dealers purchased diesel oil, some economical examinations of the diesel oil retail price, and the use of biodiesel all based on the expected economic studies in the literature studies of extra fuel consumption values.

The results of these tests indicate that the differences of consumption between diesel oils can be up to 5 %, the conclusion is that distinctions of diesel oil consumptions are almost the same when we tested the differences between diesel oil and biodiesel. This means we can reach the same result with a high quality biodiesel as with poor quality diesel oil. This also means that– below 20% of mixing ratio we can easily choose by prices alone. Between these prices and products (D1, D2, D3), we can save 4.8% diesel oil by using D2, 6.2% diesel oil by using D3 compared to D1. There could be a little revolution variance (D2: 2.9-6%, D3: 4.9- 7.1%), but this variance is under 1% so it is negligible

Keywords: *.diesel- and biofuels, internal combustion engine, engine parameters, economics*

Introduction

In the next decades, we have to take into account great changes in world politics and global economy also in the quality of power-supply and for this reason energy terms and goals also will change. The solution for the emerging problems could be the following: increasing the share of better quality or renewable fuels. Latter, not only can improve import dependence but gives many advantages for environment and society. The share of transportation is only 17% in the Hungarian energy consumption (KSH, 2013), but its importance is much bigger in costs, it's further influences pollutant emission.

Literature review

The portion of oil could be estimated 33 % of global primary energy consumption in 2012 (BP, 2012). In 2012 –because of the recession- the usage of fuel has eased down almost all over the world. Unconventional oil production has yet to yield the awaited breakthrough, lots of refineries had troubles, the safe supply of oil was in danger with talks of closing off the Hormuz-strait. Two of the most influential oil product's (Brent and WTI) margin of price grew out of proportion. In Hungary the average prices have increased because the government raised the tax, from 25% to 27% (which is the highest in Europe).The price of Brent oil examined by us (USD/barrel), was changing as shown in Figure 1.

The average price of 2012 of crude oil was 112 USD/bbl, of gasoline was 1036 USD/t, of diesel oil was 980 USD/t in term of FOB-Rotterdam (Reuters, 2013, Figure 2).

In 2012 the domestic consumption of diesel oil was 1527 million liters, it was 3% less than the previous year. This reduction was much more significant in case of gasoline (6%).

Figure 1. Brent oil price in 2012 (USD/bbl), reference: Reuters, 2013

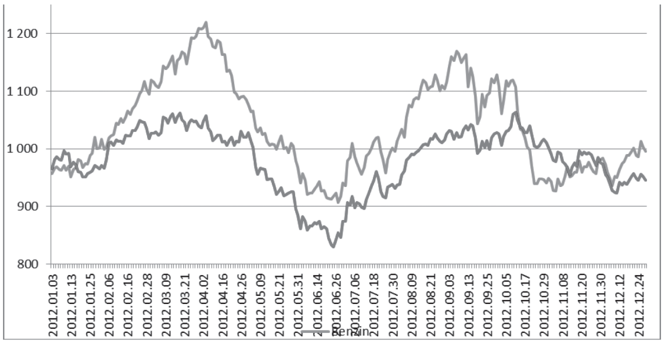


Figure 2. Price of gasoline and diesel oil in 2012 (USD/t), reference: Reuters, 2013
Note: green line: gasoline, red line: diesel oil

Table 1. Qualitative specifications of SME, RME and SyME

Specifications	Diesel oil	SME[1]	RME[2]	SyME[3]
Density (g/cm^3)	0,82–0,85	0,88	0,88	0,88
Viscosity at 40 °C (mm2/s)+	2,98	4,22	5,65	3,89
Cloud point (°C)	–12	n.a.	0	3
Flashing point (°C)	74	n.a.	120–179	–3
Sulfur content (mg/kg)	50	20	10	10
Cetene number	51–56	45–51	62	45–51
Caloric value (MJ/kg)	45,42	40,11	40,54	39,77

Reference : Hancsók, 2004 és Hancsók–Kovács, 2002 in Jobbágy (2013)

[1] SME; [2] RME; [3] SyME

The reason of this was that car owners have more rarely used their cars, but trucks and personal transport operated at the same level.

Diesel oil comes from the primary distillation of crude oil, so the quality of the crude oil properties depended on the method of distillation. Till these days the quality of diesel oil was depended on property of original crude oil and the method of distillation, but nowadays the components made by cracking have become more popular. Because of that the quality of oil doesn't matter so much (www.eni.com).

Many studies demonstrate that production and utilization of biofuels – including the vegetable oil-based fuels – are environmentally sustainable and have positive impact for the security of energy supply (Kalligeros, S. et. al, 2003, N. Kapilan et. al, 2010). However, bench testing of vegetable oil-based fuels and comparative analysis of commercially available diesel fuels (Hancsók J. et. al, 1998) should be done simultaneously to answer that under the same experimental conditions, whether there are differences in diesel fuelled internal combustion engine parameters such as torque, power and specific fuel consumption etc. (Lakatos I. 2010). Based on the answer it can be made reliable assessments, evaluations and made professional statement generally in respect of the biofuels compared to the diesel fuel parameters, and analyze the status of biofuels and their impacts on the engines and the future prospects.

According to the previous data of F. O. Licht (2012), biodiesel production was about 18.5 million t in 2012, which was 20% of total renewable fuel production, so it represented significant part of renewable energy (Jobbágy et al, 2012).

Thanks to the provisions of the Renewable Energy Directive (RED) there are ambitious targets for the use of renewable energy. These include targets for renewable energy in the road transport sector. By 2020 10% of the final consumption of energy in transport in the EU and each of its Member States should come from renewable sources. This energy could come from biomass.

However, the overall contribution of renewable energy systems in Europe are low and it is expected that the renewable energy for the 2020 target will come primarily from biomass in the form of biofuels. In 2020 it is expected that the dominant production route for biofuels will still be through the use of edible parts of plants ('first-generation' biofuels) (European Commission, 2010; O. Stoyanov, 2013; European Academies Science, 2012).

Nowadays there are only some rules in Hungary, like 30/2011, (VI.28.) NFM and 54/2012. (IX.17.) NFM direction for qualify of diesel oil and biodiesel. It means that specifications of these fuels are very similar, though density of biodiesel is a little bit higher, than the diesel oil's and according to the regulation normal diesel in Hungary has to contain minimum 6 volumetrical %, maximum 7 v% of biodiesel.

Table 1 shows differential biodiesels made of sunflower (SME), rapeseed (RME), or soybean (SyME). Caloric value of biodiesel could reach 90% of diesel oil's value, but because of 11% oxygen capacity, the firepower is more efficient, so consumption could be more only with 5-10%.

Peak torque applies less to biodiesel fuels than it does to diesel oil, but occurs at lower engine speed and generally its torque curves are flatter. Testing includes the power and torque of the methyl esters and diesel fuel and ethyl esters *vs.* diesel fuel. Biodiesels power less by 5% compared to diesel fuel at a rated load (Demirbas, 2005). Benefits and penalties of usage biodiesel motors based on literature could be summarized in the followings (Demirbas, 2005, Kisdeák, 2009; Hancsók, 2004, Moser, 2011 and Atabani et al, 2012):

- blends up to 20% biodiesel mixed with diesel fuels can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment.
- biodiesel has higher flash-point compared to diesel oil, it makes easier to transport, or store it
- it makes diesel oil more lubricant
- it oxidizes easily, this can be a problem in storage
- by mixing it with diesel oil, when engine starts in cold, biodiesel has narrow period of boiling point and this point is also high as a result,
- it can slacken engine oil because of the viscosity, engine needs some change, like special injector system
- it has oxidative character, so if biodiesel gets into the engine oil, it fast degrades that hereby decreasing oil exchange period
- it gets on fire later compared to diesel oil and it's burns almost immediately, so this gets more loading on parts of the engine
- it cause higher NO_x emission

– it could make rusty some parts (primarily copper), that could cause stanch in pipes or fuel filter, using without esterification in traditional engine prejudicing serious damages of the engine, injectors and piston rings could stuck in.

The statistically significant survey performed by Tóth (2013), mostly among consumers with primary school educations, shows much lower awareness (30% and 40%, respectively) and especially low acceptance (15%).

If we would like to use biodiesel as fuel we need to change the engine or change to diesel oil mode which requires major investment (it costs appr. 1500–5500 EUR; www.oel-alle.de). Buying of a brand new biodiesel engine is even more expensive (cca. 13000 EUR) because of the low market demand. Hungary does not have any standards for pure biodiesel (it exists only in Germany, DIN 51605).

From the 1st January 2013, the excise law (2003. CXXVII. statute) allows to farmers that they can use 97 l of produced biodiesel of their own at maximum if they pay 18% of diesel oil tax (it is now 19.9HUF/l) .

Production of biofuels are not as efficient as combustion of solid biomass, but has certainly some advantages for the variety of possible products and their nature - liquid fuels have higher energy content and can be easily stored, or transported (Boldrin et al, 2013). Future biofuel production systems should be integrated into existing technical biomass potentials. When considering the existing infrastructure of fuel distribution and fuel usage, only a reasonable mix of promising biofuels should be implemented in the energy system (Ußner-Muller, 2009).

As far as we know in Hungary distributors have never done comparative assessments about the quality of the diesel oil, but a test with gasoline in 2011 is available. In this test a Hyundai i30 with a 1400 cm^3 gasoline engine had been used which was tested by the meter instrument of the Hungaroring Driving Technique Centre. For the start of the test 5 liters of gasoline from five different companies was bought and they examined the output of the car in same, non-traffic conditions. In the comparison of the 95 octane number gasoline they get the best average usage with a gasoline from a Lukoil fuel station (7.03 l/100 km). The second was the OMV (7.09 l/100 km) and third was the Agip (7.11 l/100 km). After the leading three ones there was a little gap Shell (7,28 l/100 km) and the Mol (7.35 l/100 km). The last consumption data is 0.3 liter more than the first one Lukoil. It means almost 5% difference, which can not seem to be significant, but after 1000 kilometers there can be a 3,2 liters difference which mean a 1300 HUF saving. This difference can be interpreted in the way that the tested car with a full tank (53 litres) on a highway can travel 33 kilometres more with the best fuel. http://www.origo.hu/auto/20110520-95os- benzin-osszehasonlitoteszt.html

2. Material and Methods

In several research topics we had opportunity to perform engine tests for different purposes (study of the operational characteristic of the internal combustion engine operating on different kinds of fuels). The intention of the comparative analyzes is to determine whether there are some differences between parameters of the internal combustion engine operating commercially available diesel fuels. It is absolutely necessary to determine concrete numerical values or the range of potential differences.

In order to implement the objectives of research task the comparative analyzes were made with three different diesel fuels (D1; D2; D3) in the engine testing room. The measuring apparatus contains– Perkins 1104C type, Euro-II environmental class diesel engine with direct injection, equipped with Junkers type Schönebeck D-4 water-brake and a computer based control and evaluating system connected to it.

Engine specification:

- number of cylinders: in-line 4 cylinder
  - cycle: 4 stroke
- cubic capacity: 4.4 litres (269 cu.in.)
- combustion system: Direct Injection
- bore and stroke: 105 × 127 mm
- compression ratio: 19.3:1
- engine rotation: 1000 rpm

Performance data

- power output: 64 kW (86 bhp)
  - speed: 2400 rpm
- peak torque: 302 Nm
  - speed: 1400 rpm

The measuring apparatus available for the testing:

- Revolution measuring: ABS brake encoder together with serrated wheels, made by WABCO,
- Consumption meter: AI-2000 type (works such as measurement of mass), made by VILATI,
- Torque measuring: torque measuring cell fitted in ENERGOTEST 2000 type test bench, made by KALIBER.

The engine test was made according to directives of ECE 24 standard (Bosch Automative Handbook 2011; Dezsényi Gy. et. al., 1990), so the engine was fitted with the original intake and exhausting systems and these drove the moving parts. The measurements were made in 7 operating points between 1400 rpm and 2300 rpm. The values of torque (M), effective power (P_{eff}) and specific fuel consumption (b) were measured in case of full throttle and fixed dispenser lever position in every operating point (Dezsényi Gy. et. al., 1990; Kalligeros, S. et. al, 2003; Vas A., 1997). After selecting a given operating point the control of the measurement, together with the collection and the evaluation of the data are completely automated.

During the testing process the current values of the measured parameters were displayed steadily on the screen of the computer system connected to the test bench. The measured engine parameters were corrected according to the status indicators (temperature and pressure) of the intake air. The following correlation – suggested also by Dezsényi Gy. et. al. (1990) – could be applied to determine the corrected power:

$$P_0 = P \cdot \alpha_d \qquad [W] \qquad (a)$$

In case of diesel engines the calculated correction factors are $0.9 \leq \alpha_d \leq 1.1$. In our case the calculated value of the correction factor is $\alpha_d = 0.9839$, so the further evaluation was done with the corrected parameters.

At the specific fuel consumption -such a basic data, which need for the economic exam- in the case of reliability of the result, is rated by correlation and dispersion.

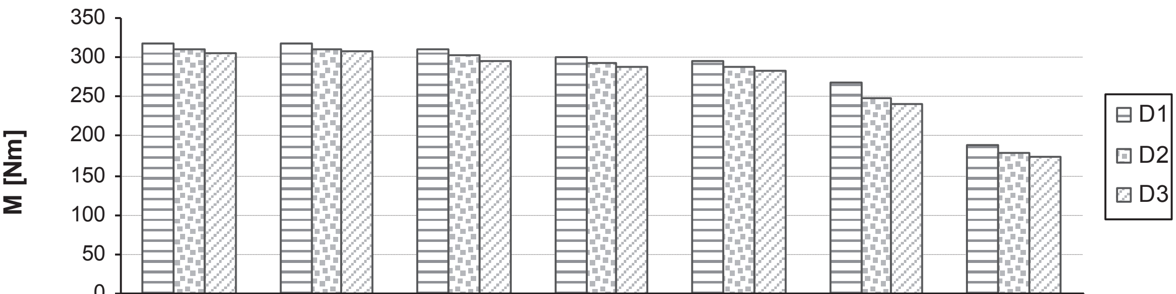
Under the economic rating in 2013 we collected the average minimum and maximum prices of the diesel oil from 3 different distributors (D1, D2, D3), which operate more than half of petrol stations of Hungary. We took into account the minimum-, maximum- and average prices of diesel oils inside and outside of Budapest and the national average of November 2013. We also rated these parameters by distributors and we made comparative analysis between the distributors. Finally – considering the difference between the prices and the qualities of the diesel oil – we defined the economical parameters of the tested diesel oils and the homogeneity of the result by using standard deviation.

Regarding the comparision of biodiesel consumption and of normal diesel we used the results of a test made by Bai et al (2008). During this experiment in 2008, 2400 l biodiesel was used by the public transport in the city of Debrecen, in blended in various mixtures into diesel (10%, 20%, 50%) and fuelled into 2 IKARUS-260 and 2 Ikarus-280 buses. The fuel consumption increased by 4,1 %, 6,5 % and 1,7 %, respectively, the average surplus consumption was 3,9 %.

3. Results and discussion

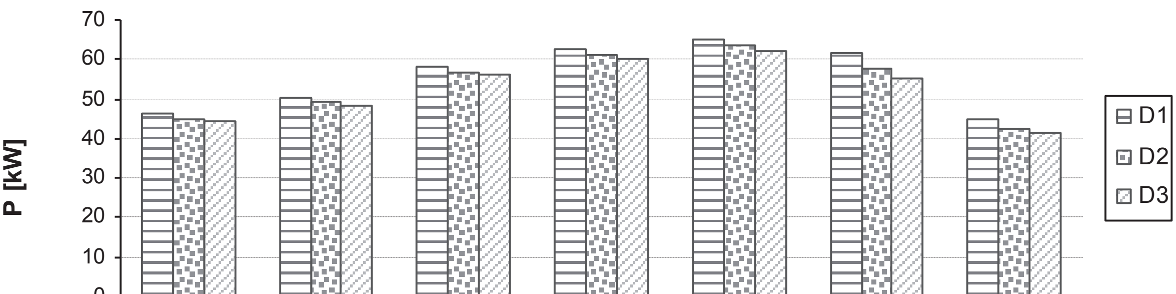
Simple bar diagrams were used to demonstrate and evaluate the numerical measurement results which definitely show the potential differences in the parameters of the engine fuelled by the diesel fuels under testing. As it can seen in Figure 3 the torque values of engine fuelled by D2 and D3 diesel fuels are lower at every measured revolution than torque values of the engine fuelled by D1 diesel fuel. The range of differences (consideration the minimum and maximum torque values at a given revolution) is from 3.15% to 10.42%. The differences of the torque values approach the lower limit of the range at lower revolutions (1400–2100 rpm), while the torque values at 2200–2300 rpm represent the higher values of the range.

The measured power values at given revolution can be seen in *Figure 3*, however the tendency is shown in the Figure 3 on the basis of $P_{eff} = M \cdot \omega$ correlation. Due to the inaccu-



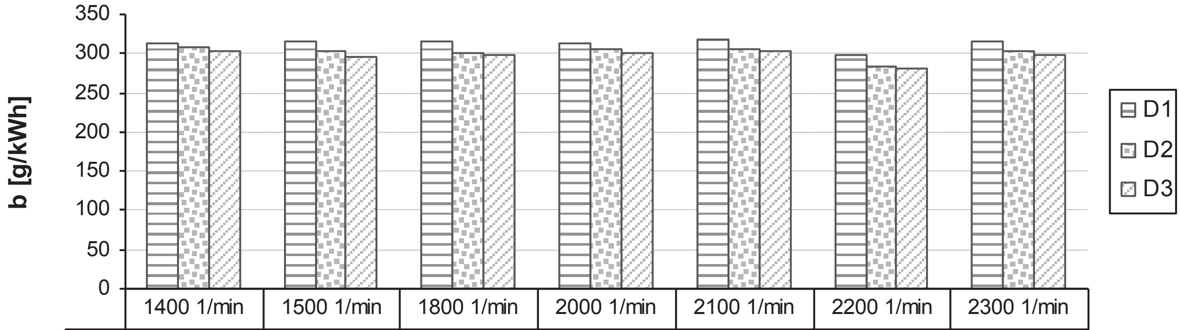
	1400 1/min	1500 1/min	1800 1/min	2000 1/min	2100 1/min	2200 1/min	2300 1/min
D1	317,5	317,5	309,4	299,7	294,6	267,9	188,8
D2	310,2	310,5	302,8	292,3	288,5	249,3	178,4
D3	305,2	307,5	296,2	287,3	282,7	240	173,3

Figure 3. Torque of the tested diesels (own test)



	1400 1/min	1500 1/min	1800 1/min	2000 1/min	2100 1/min	2200 1/min	2300 1/min
D1	46,1	50,4	58,1	62,6	65,0	61,6	45,0
D2	44,9	49,4	56,5	61,3	63,4	57,6	42,5
D3	44,5	48,1	56,4	59,9	62,0	55,4	41,4

Figure 4. Power output of the tested diesels (own test)



	1400 1/min	1500 1/min	1800 1/min	2000 1/min	2100 1/min	2200 1/min	2300 1/min
D1	314,2	314,9	314,7	312,7	316,8	298,8	315,5
D2	309,2	302,3	301,3	305,3	305	284,5	302,1
D3	302,8	296,4	297,7	300,4	302	281,1	298,1

Figure 5. Specific fuel consumption of the tested diesels (own test)

Table 2. Specific fuel consumption of D1 to the other diesel oils

Revolution 1/min	1400	1500	1800	2000	2100	2200	2300	average	SD
D1(MOL)	1	1	1	1	1	1	1	1	0
D2(OMV)	0,984	0,960	0,957	0,976	0,963	0,952	0,958	0,964	0,012
D3(AGIP)	0,964	0,941	0,946	0,961	0,953	0,941	0,945	0,950	0,009

Examining the dynamics of the particular diesel oil consumptions it can be stated that although basically the reaction to the speed growth was similar in all three cases, reaction of the D2 and D3 were almost the same to the changes of parameters (r2=0.99). In case of comparison of D1 to the others, we can see substantially bigger differences (D1/D2 r2=0.9, D1/D3 r2=0.93).

racy of the measurement the range of the difference has been changed slightly: 2.93% -10.07%. The reason of the change is explained by accuracy of the measuring system and accuracy of stored values in the background program. (Note: The displayed values are decimal precision.)

Figure 5 shows the values of the specific fuel consumption. The specific fuel consumption of engine fuelled by D1 diesel fuel exceeds at every measured revolution point the values with D2 and D3 diesel fuels. The range of deviation (based on the maximum and minimum consumption values at a given revolution) is from 3.63% to 4.68%. The average special fuel consumption was 3.6 % lower with D2 and 5% less with D3, quite reliable, because the dispersion was only about 1 % in both cases. (Table 2)

Table 3 shows the difference of the average values of the tested diesel oils and their standard deviation.

The differences between the specific fuel consumptions (3.6 %, or 5 %, in Table 2) suggests that the consumption difference between the examined diesel oils are similar to the expected difference between the diesel oil and biodiesel consumptions. This means that the same distance can be fuelled by biodiesel with standard quality than normal diesel with lower quality. This also means that the competitiveness of biodiesel (under 20 % mixing ratio) can be evaluated only by its price difference compared to the diesel oil of differential distributors.

Table 3: The averages of specific fuel consumption of differential diesel oils

	average (g/kWh)	SD
D1(MOL)	312,5	6,2
D2(OMV)	301,4	7,9
D3(AGIP)	296,9	7,4

The specific fuel consumption of a given engine depends on its operating status, loading and revolution. The effective operational range of the engine is well-determined by plotting the character field of the specific fuel consumption – so called shell curves of Alfred Jante (1976) (Gál P., 2005) – on the whole operation range. To plot the shell curves the different values of the fuel consumption concerning to different loads and effective mean pressure (p_{eff}) should be known at the given revolutions (Dezsényi Gy. et. al., 1990; Fülöp Z. 1990).

$$peff = Peff \cdot i \cdot (2 \cdot n \cdot VH)–1 \quad [Pa] \qquad (b)$$

where:
P_{eff} [W] – effective power
i [-] – number of strokes
2 – stroke constant
n [s^{-1}] – revolution
V_H [m^3] – overall stroke volume

The diagram area defined by binary function (revolution and effective mean pressure) provides the opportunity to present all the important parameters of the engine in one diagram.

Table 4. Basic data of consumer's prices of the test diesel oils

	Min.	Average	Max
Prices in the country			
MOL	401,9	420,6	462,9
OMV	405,9	419,1	438,9
AGIP	402,9	411,9	446,5
Prices in Budapest			
MOL	408,9	414,6	430,9
OMV	409,9	412,2	417,9
AGIP	403,9	411,3	429,0

Table 5. Consumer's prices compared with D1

	Min.	Average	Max	Average
Prices in the county				
MOL	1			
OMV	1,010	0,996	0,948	0,985
AGIP	1,002	0,979	0,965	0,982
Prices in Budapest				
MOL	1			
OMV	1,002	0,994	0,970	0,989
AGIP	0,988	0,992	0,996	0,992

The consumer prices collected and used for the economic studies are shown in Table 4 and Table 5. The later one contains the relative values compared to the D1. From both we might notice that the diesel oils with the better quality (leading to lower consumption) are cheaper too. Although the cheapest gas stations D1 is cheaper available, than D2, but based on the average value, D2 diesel oils are better with 0.4-0.6 % than D2, and with 0.8-2.1 % in case of D3. At the most expensive fuel stations (in the same sequence) we can see 3-5.2 % and 0.4-3.5 % difference. In Budapest there are smaller differences between the prices and they are also cheaper than the average value considering the country. If we take the average of the specific prices at several distributors (in relation to the country and Budapest) the same relative price level (0.987, so less than 1.3 %) can be experienced according to D1 diesel oil. According to the economy of the fuel consumption it could be stated that (in case of the above-mentioned consumer prices) the usage of D2 diesel oil generates 4.8 %, D3 diesel oil 6.2 % fuel cost saving compared to D1 (Table 6). Although the numbers of this is dissimilar in case of different speeds (D2: 2.9-6 %, D3: 4.9-7.1 %) but its standards deviation is so low (1 %) that statistically we can reliably expect these savings practically in every driving condition.

4. Conclusions

Whereas today the importance of the sustainable development and tenable survival is determinant, it is essential to recognize the engine parameters induced by both fossil fuels and renewable fuels from both energetic and environmental aspects that is the engine tests have to be performed with different quality fuels to facilitate to define the optimal engine operation ranges. Illustrating the parameters of an internal combustion engine fuelled by different kinds of fuels in function of the revolution presents clearly the differences due to quality properties and combustion technical parameters of the fuels. The measure parameters facilitate the energetic qualification of the used fuels.

In conclusion, we can say that the differences in the parameters of an engine fuelled with different diesel fuels can reach 10% under unfavorable conditions, beyond the all possible cases, which are significant differences in the machine operation. Therefore the engine tests performed with vegetable oil base biofuels always has to be preceded by investigations performed to define the engine parameters of the diesel fuel in order to facilitate the reliable analyzes and evaluations, furthermore to compose well-established, universal, innovative professional statements.

According to our examinations the differences between the specific fuel consumptions of the tested diesel oils can reach the 5 %. In conclusion, consumption differences between the tested diesel oils almost the same like expected consumption difference between the diesel oil and biodiesel. This means that with the same amount of lower-quality diesel oil, the same distance can be defined as the standard quality biodiesel. This also means that the competitiveness of biodiesel (under 20 % mixing ratio) can be evaluated only by its price difference against the diesel oil distributors. According to the economy of the fuel consumption it could be stated that (in case of the above-mentioned consumer prices) the usage of D2 diesel oil generates 4.8 %, D3 diesel oil 6.2 % fuel cost saving compared to D1. Although the numbers of this is dissimilar in case of different speeds (D2: 2.9-6 %, D3: 4.9-7.1 %) but its standards deviation is so low (1 %) that statistically we can reliably expect these savings practically in every driving condition.

With knowledge of the experimental results, the further direction of the research can be the elaboration of a mathematically well-manageable energetic system model, in which all the characteristics and parameters influencing the energetic operators can be taken into consideration, of course observing the priority requirements. It can be determined that further researches are needed to compare systematically the environmental and energy performance of biofuels.

Table 6. Costs of fuels of D2 and D3 compared with D1

Revolution 1/min	1400	1500	1800	2000	2100	2200	2300	average	dispersion
D1	1	1	1	1	1	1	1	1	0
D2	0,971	0,947	0,945	0,963	0,950	0,940	0,945	0,952	0,011
D3	0,951	0,929	0,934	0,948	0,941	0,928	0,933	0,938	0,009

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