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Durability test on an agricultural tractor engine fuelled with pure biodiesel (B100)

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Abstract: The performance of a 118-kW tractor fuelled by pure biodiesel was monitored during a long-term field experiment with approximately 800 h of engine function. The objective was to demonstrate that B100, a pure biodiesel fuel, is a viable alternative to traditional diesel oil in terms of long-term mechanical reliability. A bench test on the new engine, performed by attaching a test stand to the power take-off of the tractor, showed an expected reduction in power (–9%) and torque (–7%) and an increase in specific consumption (+13%) when biodiesel was used as a complete substitute to diesel oil. Furthermore, with the same setup, the exhaust gas had a Bosch smoke index equal to 50% of the value for the same engine fuelled with diesel oil. After these initial tests, the tractor was set up for normal field operations, in which both the engine curves and lubricant quality were periodically monitored. These surveys indicated no significant reduction in engine performance; however, the lubricant was consequently diluted and contaminated by biodiesel, which caused the lubricant properties to considerably worsen. However, on the basis of the chemical–physical analysis, reducing the oil change interval from 200 h (manufacturer's indications for the engine when operating with diesel oil) to 100 h would compensate for this progressive quality decline. At the end of the trials, the engine was disassembled to check the condition of its components; wear and lacquer-like coating phenomena were observed, and their levels were acceptable. The obtained results demonstrated that B100 can effectively substitute for diesel oil in a standard compression-ignition engine: the power change is not perceptible during normal operation of a tractor, and no particular problem will arise in the engine during its life if the lubricant is changed every 100 h.

Key words: Agricultural tractor, B100, biodiesel, diesel engine, durability tests, engine performance

1. Introduction

The mechanization of agriculture, and in particular the introduction of the tractor as a substitute for pack animals in the heaviest agricultural tasks, brought a strong development to this sector by increasing both the yield productions and the working capacities of the involved people. From this radical change, often not accompanied by an appropriate change in mentality of the operators, new problems arose and, consequently, the attention of researchers has also been focused on man–machine interactions and machines rather than on crops. On the one hand, there is surely a great need for work on the problem of making machines safer, as today they are the main source of agricultural accidents such as overturning (Ahmadi, 2013); on the other hand, there are lots of studies concerning the efficiency of the engines and transmissions of tractors (Molari and Sedoni, 2008; Bietresato et al., 2012) or the pollution produced by agricultural engines.

Several experiments have shown the environmental benefits resulting from the use of biodiesel instead of diesel oil, although in the present world scenario, completely replacing fossil fuel is impossible. Moreover, in developed countries, the production of oilseeds for biodiesel production can contribute to the economic requalification of rural areas, which today are experiencing reduced incomes and dwindling populations.

Biodiesel can be produced using both vegetable oils and animal fat; thus, it is renewable, biodegradable, and nontoxic (Barnwal and Sharma, 2005; Bozbas, 2008; Karonis et al., 2009; Janaun and Ellis, 2010; Lozada et al., 2010). Oils and fats are triglycerides, i.e. they are made of 3 long chains of fatty acids (Jain and Sharma, 2010a; Mata et al., 2010; Singh and Singh, 2010) and are characterized by high viscosity (Tat and Gerpen, 1999; Kinast, 2003; Joshi and Pegg, 2007; Alptekin and Canakci, 2008). Because a high viscosity is not compatible with compression-ignition engines (diesel-cycle engines), it is necessary to convert the triglycerides in fatty acids through a transesterification reaction using a basic catalyst (typically sodium hydroxide). By doing so, 2 components can be produced:

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- an ester (methyl or ethyl ester, depending on the involved reagents), usable as a fuel for compression-ignition engines and having a viscosity similar to (or slightly greater than) diesel oil, commonly called “biodiesel” for this reason;
- glycerol (or glycerin), denser than the previous substance and therefore easily separable by sedimentation.

When biodiesel burns in compression-ignition engines, it produces pollutants that are less harmful to human health (Lin and Lin, 2006; Mamat et al., 2009) and to the environment than traditional diesel oil (particularly referring to particulates and carbon dioxide). Moreover, the engine thermal efficiency does not change and can even improve slightly (Murillo et al., 2007; Raheman and Ghadge, 2007; Szybist et al., 2007; Haşimoğlu et al., 2008; Nabi et al., 2009; Qi et al., 2009; Ryu, 2010; Aybek et al., 2011); however, engine power is reduced (Özkan et al., 2005; Nabi et al., 2009; Qi et al., 2009; Altun, 2011) due to biodiesel lower calorific value and higher viscosity (Szybist et al., 2007; Haşimoğlu et al., 2008). In fact, the viscosity of biodiesel is extremely high at 25 °C, reaching up to 1.6 times the diesel oil viscosity up to 40 °C (Tesfa et al., 2010). In particular, the higher viscosity is responsible for the considerable alterations in the engine fuelling because it causes higher fuel pump head losses and hence lower fuel flow rates and a worse pulverization of the injected fuel, evident from the lower Sauter mean diameter of the fuel drops (Tesfa et al., 2010). Technically speaking, all these effects result in longer delays in fuel ignition (Xue et al., 2011) and change the heat release rate curve, the pressure curve, and the exhaust gas temperature (Utlu and Koçak, 2008; Aydin and Bayindir, 2010; Xue et al., 2011). As a consequence, the brake specific fuel consumption (BSFC) increases (Ramadhas et al., 2004, 2005; Özkan et al., 2005; Haşimoğlu et al., 2008; Altun, 2011), though the smokiness lowers to 50% (Utlu and Koçak, 2008; Qi et al., 2009; Pal et al., 2010; Xue et al., 2011) due to the increased availability of oxygen in the biodiesel, which promotes the combustion process and soot oxidation (Qi et al., 2009; Xue et al., 2011). From a technical point of view, the modifications to engines to be powered by biodiesel are minimal if not absent (Meher et al., 2006; Fazal et al., 2011). However, because biodiesel has an oxidant potential greater than that of diesel oil, it can potentially cause greater corrosion (Sgroi et al., 2005; Tsuchiya et al., 2006; Jain and Sharma, 2010b), although the engine wear is similar to that observed when using traditional diesel oil (Dorado, 2003; Khan et al., 2009). Finally, it has solvency properties for several types of polymeric materials, which means it can cause structural degradation (Gonzales Prieto et al., 2008; Trakarnpruk and Porntangjitlikit, 2008; Haseeb et al., 2010).

Regarding the durability of engines fuelled with biodiesel/diesel-oil blends, there have been studies (Fosseen Manufacturing & Development, 1995; Ortech Corporation, 1995; Graboski and McCormick, 1998; McCormick et al., 2005; Rojas, 2008) where several problems have occurred (injector coking, filter plugging, piston-ring sticking, and engine deposits) when poor blends were used (B20, with 20% biodiesel); however, in other durability field tests, no particular problems occurred apart from filter plugging and injector coking, and engine wear was standard (Chase et al., 2000; Kearney and Benton, 2002; Proc et al., 2006). In these cases, B20, B50, and B100 blends were used.

The aim of this study was to perform an 800–h durability field test on a compression-ignition engine normally used in a medium to high-powered agricultural tractor (118 kW), fuelled by pure biodiesel (B100). The general conditions of the engine during the test were verified indirectly by monitoring its performance over time. Power, torque, and BSFC curves were periodically measured via an engine test stand comparing to corresponding curves of a new engine. Other direct verifications were performed: the chemical composition of the lubricating oil was analyzed at stated time intervals and before every change, and the surface conditions of the many mechanical components of the engine were checked at the end of the durability test and after the engine was completely disassembled.

2. Materials and methods

The experiment was performed on an engine with the characteristics reported in Table 1 and included many tests depending on the elapsed time:

- At the beginning of the experimental activities (1st phase), the performance curves (power, torque, and BSFC) and the smokiness of the same engine alternatively fuelled with diesel oil and with biodiesel were recorded; the equipment included a hydraulic mobile test (Table 2) attached to the power take-off (PTO) of the tractor; a power output extremely close to the power effectively available to the tires was therefore recorded (unlike the SAE protocols prescriptions used by the engine manufacturers to indicate nominal power; according to these protocols the engine is isolated from the rest of the vehicle and without most of the auxiliaries); the fuel pump rack was fully opened in both cases, i.e. the tests began from maximum engine speed and with an increasing brake force to obtain the part-load and full-load curves at a rated engine speed; the BSFC was measured using a chrono-gravimetric method, and the smoke index was measured using a Bosch diesel smoke meter (Table 2).
- During the course of the experiment (2nd phase), the performance of the engine was checked at regular intervals using the same dynamometer and with the same test protocol (fully opened fuel pump rack and dynamometer connected at the PTO); samples of the lubricant (1 L per sampling) were also taken to be analyzed in laboratory.

Table 1. Technical characteristics of the engine used in this study.

Description	Unit	Specifications
Manufacturer, type	–	Fiat 8365.25, turbocharged, with direct injection
Cylinders, configuration	nr	6, straight and vertical
Bore, stroke	mm, mm	115, 130
Total displacement	cm^3	8102
Volumetric compression ratio	–	15.5:1
Nominal power (SAEJ1995)	kW	118
Nominal engine speed	rpm	2200

Table 2. Test equipment used in this study.

Test equipment, manufacturer, model	Technical specifications	Other specifications
Hydraulic mobile test stand, M&W Gear (Gibson City, IL, USA), P-400M hydra-gauge dynamometer	• Full scale values: gauge pressure of 14,000 kPa (140 bar) PTO shaft speed of 1400 rpm • Resolution: 200 kPa (2 bar) 10 rpm • Oil operative temperature: 140–180 °F (60–82 °C)	• Manually operated through a hand-wheel acting on a valve which increases the counter pressure on a volumetric pump driven by the tractor PTO (operative fluid: oil); hence, the breaking load on the tractor • Equipped with an internal water–oil radiator for cooling (requires a temporary connection with the water mains) • Provided with a pressure–power (kPa–kW) calculator
BSFC measurement equipment	• Full scale: 20,000 g • Resolution: 1 g	• Diesel oil tank on a precision balance • Functioning principle: chrono-gravimetric
Diesel smoke meter, Robert Bosch (Stuttgart, Germany), MED001	• Ranges: opacity of 0.0%–99.9%, absorption coefficient (K-value) of 0.00–9.99 m^{-1} • Resolution: 0.1%, 0.01 m^{-1}	• Functioning principle: photoelectric measurement of the light reflected by a blackened filter paper

- At the end of the experiment (3rd phase), the engine was completely disassembled to check the condition of the different mechanical parts.

The biodiesel used during the test was a commercial pure fatty acid methyl-ester (FAME) with a lower heating value of 36.0 MJ kg^{-1}. Its physical–chemical parameters met the requirements of the main EU standard concerning biodiesel fuel for automotive traction (EN 14214:2008; Table 3).

3. Results

Figure 1 shows the performance curves of the engine at the beginning of its operative life, fuelled with diesel oil and then with biodiesel. Figure 2 reports the Bosch smoke index of the exhaust gases at different engine speeds and with the fuel pump rack fully opened, i.e. beginning from the speed corresponding to the maximum power output (2200 rpm), and recorded simultaneously with the performance curves of the engine fuelled with diesel oil and then with biodiesel.

Figure 3 shows the performance of the same engine fuelled with B100 and recorded after 4, 50, and 180 h of functioning, i.e. at the beginning of its life and after 2 complete substitutions of the lubricant. Figure 4 shows the engine characteristic curves after 4, 630, and 780 h of operation. The relevant values of the engine characteristic curves recorded over the entire observation period of 780 h are shown in Table 4.

The observation period ended after 780 h of engine operation with pure biodiesel, and during this period, the farm tractor was used in typical operations of an agro-zootechnical farm (therefore it underwent various operating modes); the objective of this was to reflect normal use of such a tractor and to estimate a realistic lubricant change interval without using a standard cycle (normally used only for homologating a motor with respect to current norms).

Table 3. Main characteristics of the biodiesel used.

Property	Unit	Value	Requirements	Test method	Standard
FAME content	%	98.0	≥96.5	EN 14103	EN 14214:2008
Density at 15 °C	kg m^{-3}	882	860–900	EN ISO 3675 EN ISO 12185	EN 14214:2008
Kinematic viscosity at 40 °C	mm^2 s^{-1}	4.5	3.5–5.0	EN ISO 3104	EN 14214:2008
Flash point	°C	107.0	≥101.0	EN ISO 2719 EN ISO 3679	EN 14214:2008
Pour point	°C	–14.0	0	ISO 3016	EN 14213:2003
Carbon residue (on 10% distillation residue)	%	<0.30	≤0.30	EN ISO 10370	EN 14214:2008
Cetane number	–	53	≥51	EN ISO 5165	EN 14214:2008
Iodine value	g(iodine)/(100g)	118	≤120	EN 14111	EN 14214:2008

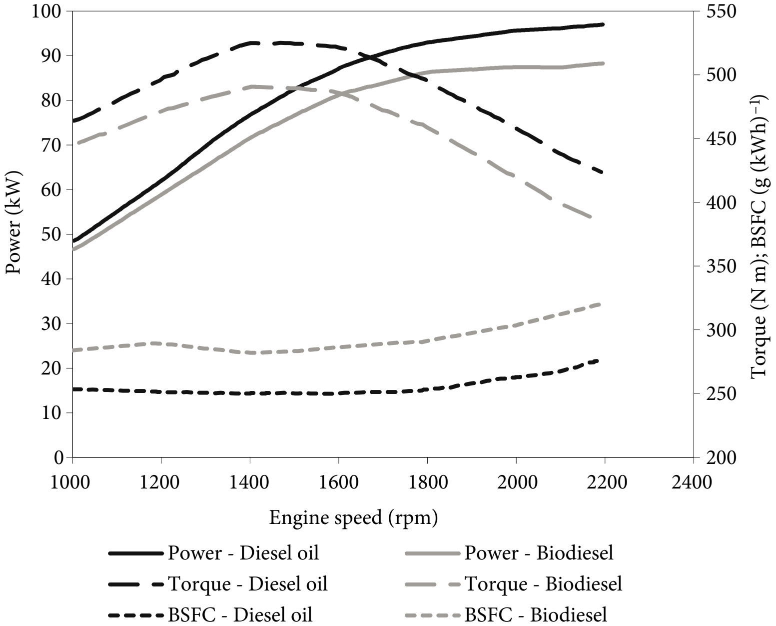

Figure 1. Performance curves of the engine fuelled with biodiesel and diesel oil.

Finally, Tables 5 and 6 report the physical–chemical characteristics of the lubricant used during the experimentation (SAE 15W-40 multi-grade engine oil) from before use and after the indicated periods (samples taken from the oil sump).

4. Discussion

4.1. Beginning of the experiment: comparative tests between diesel oil and biodiesel in a new engine

By observing the curves represented in Figure 1, it is evident that there was a reduction in power (the maximum value dropped from 97 to 88 kW at 2200 rpm: –9%) and in engine torque (the maximum value dropped from 525 to 491 Nm at 1400 rpm: –7%) when fuelled with biodiesel; the crankshaft speeds corresponding to the maximums are the same with diesel oil and biodiesel. There was also an increase in the BSFC of 16%, from 276 to 320 g (kW h)$^{-1}$, at an engine speed corresponding to maximum power, or 13%, if comparing the minimum values (from 249 to 282 g (kW h)$^{-1}$ at 1520 and 1400 rpm, respectively). The reason for the decreases in power and torque was the lower calorific value of biodiesel (National Biodiesel Board, 2005; CTI - Comitato Termotecnico Italiano, 2013). The increase in BSFC (Utlu and Koçak, 2008; Aydin and Bayindir, 2010) is the result of both the different lower calorific value of biodiesel (hence, of the engine power) and of biodiesel

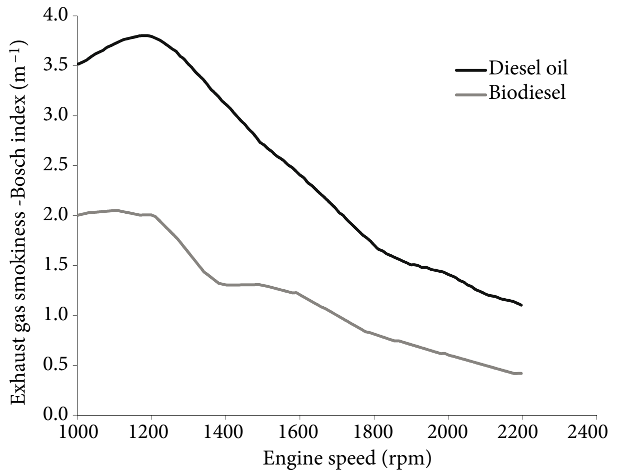

Figure 2. Smokiness of the same engine fuelled by diesel oil and biodiesel.

reduced inclination to evaporate compared to diesel oil (Szybist et al., 2007; Haşimoğlu et al., 2008), which is also the cause behind the longer delays in fuel ignition and the changes in the heat release rate and pressure curves (Xue et al., 2011). Figure 2 shows that a biodiesel-fuelled engine has a smokiness that is approximately half of the diesel-oil-fuelled engine throughout its entire operative range, due to the higher oxygen content of biodiesel (Murillo et al., 2007).

4.2. Course of the experiment: field tests on the engine fuelled with pure biodiesel only

In regards to the first operative period of the engine (4, 50, and 180 h; Figure 3), the measures showed slight increases in all the performance parameters throughout the engine operative range (particularly at 1550–2250 rpm), primarily due to a change in the environmental temperature that occurred in the period corresponding to reaching 50 and 180 h of operation for the engine (from winter to summer). The recorded temperature increase was approximately 30–35 °C and had important repercussions on the biodiesel viscosity (Kerschbaum and Rinke, 2004; Bhale et al., 2009; Tesfa et al., 2010) and hence on the pulverization capability of the injection system on the biodiesel (Tesfa et al., 2010). More detail as follows:

- The maximum value of the power increased from 89 to 93 and 96 kW corresponding to +4% and +8% at engine speeds between 2070 and 2170 rpm, respectively.
- The maximum value of the torque increased from 488 to 499 and 508 Nm corresponding to +2% and +4% at a maximum torque engine speed shifting from 1410 to 1510 and 1620 rpm, respectively.
- The minimum BSFC decreased from 274 to 272 and 263 g (kW h)$^{-1}$ (–4%), with the corresponding engine speed unchanged (1370 rpm).

Figure 4 shows the performance curves recorded at 630 and 780 h compared with the curve at 4 h; based on the graph and the values in Table 4, if the performance of the

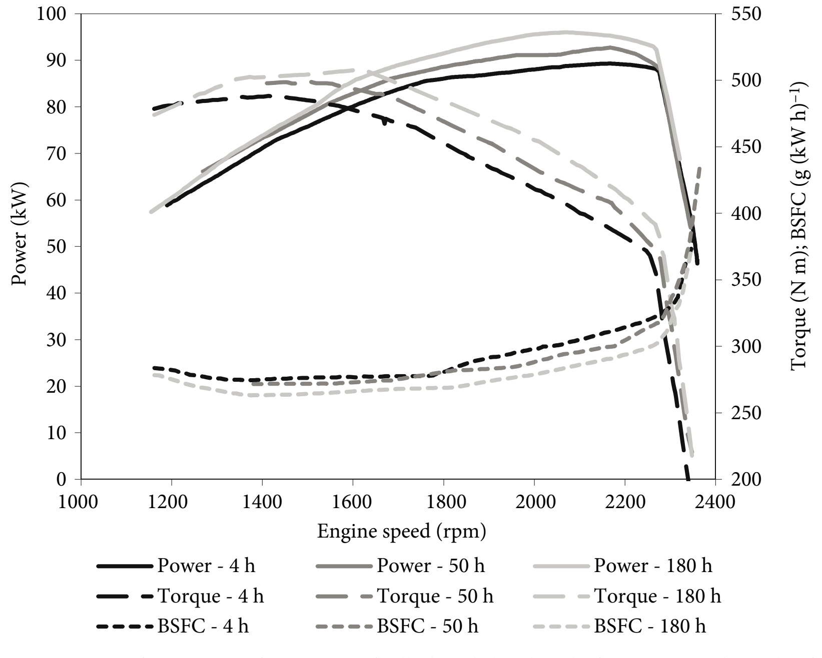

Figure 3. Performances of an engine fuelled with biodiesel after 4, 50, and 180 h of operation.

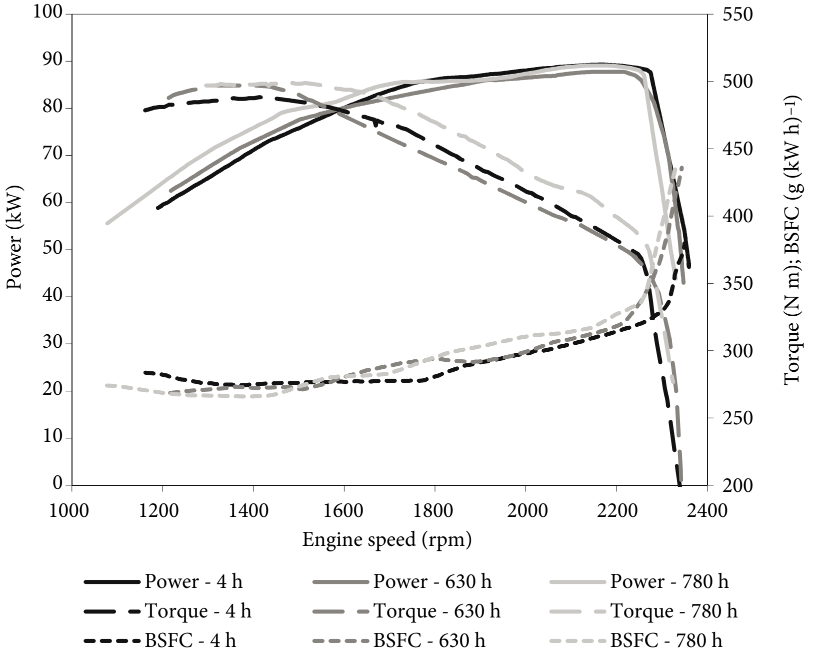

Figure 4. Engine performances fuelled by biodiesel after 4, 630, and 780 h of operation.

Table 4. Characteristics of the tested engine at different operative times; the percentage differences refer to the values at 4 h.

Elapsed operative time (h)	Engine speed (rpm)		Power (kW)		Torque (N m)		BSFC (g (kW h)$^{-1}$)	
	Max power	Max torque	Maximum	At max torque	Maximum	At max power	At max power	At max torque
4 (ref.)	2170	1410	89.3	72.3	488.2	393.5	310.8	275.3
50	2170	1510	92.7 (+4%)	78.7 (+9%)	498.7 (+2%)	408.6 (+4%)	299.6 (–4%)	271.9 (–1%)
180	2070	1620	96.0 (+8%)	86.1 (+19%)	507.6 (+4%)	442.5 (+12%)	283.5 (–9%)	273.2 (–1%)
630	2210	1400	87.7 (–2%)	72.8 (+1%)	497.0 (+2%)	379.6 (–4%)	319.1 (+3%)	272.5 (–1%)
780	2170	1440	89.1 (+0%)	76.7 (+6%)	508.3 (+4%)	392.3 (+0%)	320.7 (+3%)	266.7 (–3%)

engine at 4 h is used as a reference, the following can be observed:

- A substantial constancy of engine power (differences are within –2% for the maximum power, respectively 89, 88, and 89 kW at 2170–2210 rpm).
- A slight increase in maximum torque (from 488 Nm at 4 h to 497 and 508 Nm at 630 and 780 h, so +2% and +4%, respectively).
- A significant consistency in the BSFC throughout the entire engine operative range (percentage differences with opposite signs at the inquired engine speeds were between –3% and +3%) with the minimum value substantially unchanged (from 275 to 273 and 267 g (kW h)$^{-1}$, –1% and –3%, respectively, at 1400–1440 rpm).

The tests performed at 630 and particularly at 780 h were performed at the end of the experiment, i.e. after an entire solar year with an ambient temperature extremely close to the temperature that occurred during the first test at 4 h (it was winter in both of these periods). This fact is responsible for the similitude of the biodiesel viscosity and the pulverization obtained by the injection system (Tesfa et al., 2010) and therefore of the substantial equality

Table 5. Lubricant characteristics at different periods.

Type	Units	Test method	Lubricant hours (engine hours)				
			New lubricant	60 (60)	120 (180)	260 (440)	190 (630)
Dynamic viscosity at 40 °C	Pa s	ASTM D 445	0.0946	0.0469	0.0402	0.0445	0.0679
Difference of viscosity at 40 °C	%		–	*	−57.5	−53.0	−28.2
Dynamic viscosity at 100 °C	Pa s		0.0127	0.0079	0.0073	0.0071	0.0101
Difference of viscosity at 100 °C	%		–	*	−42.6	−43.9	−20.6
Water	%	ASTM D 322	traces	traces	traces	traces	n.a.
Dilution by biodiesel			–	12.91	15.73	9.25	n.a.
Total sludge		FIAT 50523	–	0.20	0.42	10.09	1.90
Deposit-forming sludge				0.06	0.06	9.04	0.70
Lacquers				0.04	0.06	8.76	1.20
TAN	$mg_{(KOH)}\ g^{-1}$	ASTM D 664	2.44	4.69	5.28	25.46	7.36
TBN			10.00	6.88	5.13	2.10	4.45

* = run-in lubricant, and n.a. = data not available.

Table 6. Lubricant characteristics at different periods.

Type		Units	Test method	Lubricant hours (engine hours)				
				New lubricant	60 (60)	120 (180)	260 (440)	190 (630)
Metal particles in suspension	Al	ppm	–	–	8	7	none	5
	Cr			–	3	3	none	2
	Fe			–	23	23	27	48
	Mn			–	3	1	none	none
	Mo			–	none	none	none	none
	Pb			–	10	8	2239	470
	Cu			–	15	10	468	255
	Si			–	17	14	9	9
	Sn			–	none	none	10	3
Ferrography	Large (>5 µm)	–	Direct reading	–	13.5	17.9	108.0	54.4
	Small (<5 µm)			–	6.9	7.1	93.0	29.1
	Wear severity index (WSI)			–	134.6	270.0	3015.0	2112.6

* = run-in lubricant, and n.a. = data not available.

of the recorded engine performances. This is also the reason behind the worsened performances at 630 and 780 h compared with the performances obtained during the summer period (maximum power −5%, from 93 to 88 and 89 kW; BSFC +7%, from 300 to 320 and 321 g $(kW\ h)^{-1}$).

Finally, from the values of Table 4 and by observing that the engine curve at 780 h is superimposed on the 4-h curve, we determined that the engine performances were substantially stable over time; therefore, a prolonged usage of biodiesel did not lead to significant changes in engine parameters.

4.3. Course of the experiment: periodic analyses of the engine lubricant

Observing the values reported in Tables 5 and 6, the following can be affirmed:

- With respect to the new lubricant, a clear reduction in viscosity was found in all samples, contrary to what is normally observed with diesel oil; this phenomenon can be ascribed to the dilution of the lubricant operated by the biodiesel (the higher viscosity and consequent worse pulverization of this fuel resulted in more droplets arriving on the combustion chamber walls, where they are intercepted by the oil-scraper piston ring).
- The total and deposit-forming sludge and the lacquer-like coatings, which give an indication of the thermal-oxidative degradation of the lubricant, did not increase excessively, apart from the sample taken at 440 h; however, the engine manufacturer considers up to 4% of total sludge and 0.6%–0.8% of lacquers acceptable, and therefore these values are of no concern.
- The total basicity number (TBN), which expresses the capability of the lubricant to neutralize the acid compounds generated by combustion and lubricant degradation, normally reduces with operation time; this phenomenon was observable in this experiment. TBN values of the used lubricant are considered acceptable if greater than half the value of a new product; therefore, the samples taken at 440 and 630 h of operation have an excessively reduced index value.
- The total acidity number (TAN) provides an indication of the amount of acid products formed as a result of the lubricant degradation and can also be nonzero in new lubricants, as in the present case, due to the presence of additives and acid compounds in the mineral base; a lubricant should be changed when the TAN value exceeds the residual TBN value. In particular, the high TAN value of the 440-h sample together with the high sludge and lacquer values of the same sample indicate a strong degradation of the lubricant.
- The metals subjected to wear (in particular, copper and lead used for the bearings) reached particularly high values in the samples taken at 440 and 630 h. The wear values obtained for lead and copper must be considered a consequence of low viscosity (and of the consequent problem related to the lubricant film formation) and also of an acidic attack to these metals related to high TAN oil values.
- A direct-read ferrographic analysis showed high values of the wear severity index (WSI) for the aforementioned 440-h and 630-h samples, and hence of the wear in the parts in contact with relative motion.

4.4. End of the experiment: analysis of the mechanical components of the engine

At the end of the 780-h test, the engine was disassembled and all of its components were carefully analyzed in a specialized laboratory. In particular, from this analysis, the following emerged:

- The valves, cylinders, and pistons were in good condition with regard to carbon deposits; however, the pistons presented a particularly thick lacquer-like coating.
- The rod bearings showed clear, although acceptable, traces of mechanical damage; this phenomenon is likely due to the reduced lubricating characteristics of the lubricant diluted by the biodiesel.
- Several components of the engine presented various types of deposits (sludgy and nonsludgy).
- A notable amount of sludge was present on the base of one of the 2 lubricant filters even though it did not cause any malfunction to the system. During the experiment, other components of the fuel system (water separator and fuel filter) were substituted and analyzed and did not manifest any problem due to the use of biodiesel.

4.5. Final comments

To investigate the medium- and long-term effects of pure biodiesel on the operation and on the components of an agricultural tractor, a series of tests were performed over 780 h (characteristic curves recordings, chemical–physical analyses of the lubricant, and visual inspection of engine components).

The use of biodiesel in a compression-ignition engine causes an expectable decrease in the engine performance compared with the same system fuelled by diesel oil (–9% of maximum power and +13% of minimum BSFC) due to the chemical differences in the molecular structure of these 2 fuels.

Notwithstanding this fact, biodiesel proved to be suitable for fuelling this type of engine for an extended period because it does not cause any decrease in performance over time. In fact, after 780 h, the tests showed no reduction in the maximum engine power and even a slight increase in the maximum torque (+3%).

The analyses on the lubricating oil showed a progressive reduction in the lubricant viscosity caused by a dilution operated by biodiesel, likely responsible for the observed increase in the amount of wear particles, lacquers, and sludge after 440 h (evidenced by TAN, TBN, and WSI values).

The complete disassembly of the engine at the end of the experiment allowed the observation that the valves and cylinders were in perfect condition, even if there was slight wear on the crankshaft bearings, some accumulation of lacquer and carbon on the pistons, and large amounts of sludge on different parts; all of these indicators were normal and comparable with a prolonged use of diesel oil in similar engines.

In conclusion, the results from these analyses demonstrated that the use of pure biodiesel as a fuel in a standard engine gives no particular technical problem either to the engine itself or the motor oil as long as the oil is changed every 100 h (during the test it was changed approximately every 200 h of operation, which is the time interval suggested by the tractor manufacturer when the engine is fuelled by diesel oil). The power changes are completely negligible and imperceptible during normal operation of such a tractor. Biodiesel can therefore be an effective substitute for traditional diesel oil. The environmental benefits derived from the use of this fuel, which are well known in the literature, are balanced by the increase in the maintenance costs due to reducing the lubricant substitution time interval by half. Therefore, apart from the technical feasibility, which was evaluated here, the framework emerging from this article is complex and definitely deserves careful evaluation by farmers before they change the fuel in their tractors.

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