



## Full Length Article

# Comparative evaluation of physical and chemical properties, emission and combustion characteristics of brassica, cardoon and coffee based biodiesels as fuel in a compression-ignition engine



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## ABSTRACT

This study have been considered the effects of the three type of biodiesel (brassica, cardoon and coffee) on the performance, tailpipe emissions and combustion characteristics of a single cylinder direct injection compression ignition engine operated in four different speeds (1200, 1700, 2200, 2700 rpm) and three different engine loads (15, 30 and 45%). The differences in combustion and performance parameters and exhaust emissions of engine fueled by these fuels have been compared. The free fatty acid profile of the biodiesels has been considered. The properties of the biodiesels according to the ASTM D6751 have been analyzed. Highest degree of unsaturation is achieved for biodiesel produced from brassica (94.64%) compared to biofuels derived from cardoon and coffee, 79.81% and 57.65%, respectively. The high value of the erucic acid (C22:1) in the brassica biodiesel (48.7 wt%) is the reason of higher unsaturation degree than the other biodiesels. The components of the free fatty acid profile of the considered biodiesels mostly include long chain free fatty acids (C18 and higher). The physical properties of the biodiesel fuel is influenced by the fatty acid profile. The CN of the brassica, cardoon and coffee is 56.44, 56.11 and 57.44, respectively. The surface tension of the brassica, cardoon and coffee biodiesel fuel is 42.05, 40.99 and 37.62 mN/m. The oxygen content of the brassica, cardoon and coffee is 13.44, 10.91 and 7.77%, accordingly. Dynamic viscosity of the brassica, cardoon and coffee was 6, 5.7 and 9.5 cSt, respectively. The ignition delay of the brassica, cardoon and coffee biodiesel diesel fuel blends at 15% engine load is 9.52, 11.05, 5.07% and at 30% engine load is 12.88, 13.85, 15.78% lower than diesel fuel on average, respectively. The additional oxygen have decreased the CO and THC emissions. The highest reduction of the THC emission than standard diesel fuel was 41.19%. The maximum BTE (brake thermal efficiency) obtained for different biodiesel diesel blends fuels was lower than that of standard diesel fuel. The CA50 of the biodiesel diesel fuels was lower than diesel fuel due to their lower ignition delay.

## 1. Introduction

Nowadays, increasing the oil prices, insufficiency of its reserves and greater restrictions on emissions of pollutants imposed on automakers, led to the scientific research to play an increasingly active role in assessing the use of biofuels as an alternative to petroleum products. In this context, the biodiesel is applicable solution immediately. The biodiesel is a biofuel obtained from oil by a transesterification process, consisting of a mixture of methyl esters of long chain fatty acids with similar chemical and physical characteristics to those of the diesel fuel [1]. The term biofuels includes all those substances, of vegetable or

animal origin, able to produce energy. In this category fall biofuels, obtained from biomass, which can be used for the feeding of internal combustion engines [2]. The main reason that prompted the research in this direction is renewability of biodiesel. In fact, the balance of CO<sub>2</sub> emitted during the entire cycle of biodiesel (i.e. cultivation, production and use) is more beneficial than traditional diesel fuel [3]. As reported in the literature, the regulated emissions of biodiesel appeared to be generally lower than those affecting traditional fuel engines. However the amount of nitrogen oxides emissions is strongly dependent on the amount of oxygen present in biodiesel molecule [4,5]. From an energy point of view, the use of biodiesel entails a slight decrease in power and

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**Table 1**  
Bio-fuel statistics effects on engine emission and performances [13].

Total number of references		Increase		Similar		Decrease	
		Number	%	Number	%	Number	%
Power	77	2	7.4	6	22.2	19	70.4
PM emissions	73	7	9.6	2	2.7	64	87.7
NO <sub>x</sub> emissions	69	45	65.2	4	5.8	20	29.0
CO emissions	66	7	10.6	2	3	57	84.4
HC emissions	57	3	5.3	3	5.3	51	89.5
CO <sub>2</sub> emissions	13	6	46.2	2	15.4	5	38.5

an increase of specific fuel consumption which is attributable to a lower calorific value of biodiesel compared to diesel fuel [5].

The researches on finding new suitable sources to production of the biodiesel is ongoing. Sajjadi et al., [6] introduced 29 edible sources (such as sunflower [7], corn [8] and canola [9]) and 43 nonedible sources (such as castor [10], kranja [11] and jatrophia [12]) which have been studied to biodiesel production.

Xue et al., [13] considered different researches on engine emission and performance (Table 1) and summarized that 70.4% researchers have agreed that engine power can be dropped with biodiesel as fuel due to the lower LHV of biodiesel, 87.7% agreed on decrease in PM, 65.2% agreed on increase in NO<sub>x</sub>, 84.4% agreed on decrease in CO, 89.5% agreed on decrease in HC and 46.2% agreed on increase in CO<sub>2</sub>.

The most important properties of the biodiesel fuel which are effective on the engine performance, combustion and engine emission are kinematics viscosity, lower heating value, cetane number and oxygen content. Lower heating value of the biodiesel is lower than diesel fuel and kinematics viscosity, cetane number and in other hand oxygen content of biodiesel is higher than diesel fuel [14]. High viscosity will increase the soot formation and engine deposit due to insufficient atomization. It is observed that this parameter is higher for biodiesel compared to diesel and it is increases as the content of saturated fatty acids increases. Furthermore, the viscosity of the biodiesel is proportional to the length of the fatty acid chains, so the reaction of transesterification is configured as a critical factor, as such reaction breaks the triglyceride molecule to form three molecules of methyl esters, smaller and, as is said, less viscous [15]. The dynamic viscosity has been the most effective parameter on the fuel injection properties such as SMD. The SMD of the injected fuel increased by increasing in the fuel viscosity [16]. The energy density (i.e. the lower calorific value, LHV) of biodiesel is lower than diesel fuel because its molecule contains on average about 10% (wt%) oxygen. This oxygen content of biodiesel makes possible complete combustion. It shows that in terms of combustion efficiency biodiesel offers a better performance than which is offered by the diesel fuel [17].

Filling a gap of the relevant literature, this study presents a research on the effect of three different type of biofuels on emission, performance and combustion characteristics of a single cylinder engine. Biodiesel derived from waste coffee, brassica and cardoon are used in blends with diesel fuel in the various engine speed and load in a DI (direct injection) diesel engine, under the same operating conditions. To the authors' knowledge this is the first time that such a comparison is reported for these bio-fuels diesel fuel blends. Specifically, the comparative evaluation is carried out on a common solid basis (engine and operating conditions) concerning combustion, performance (specific fuel consumption, brake thermal efficiency) and all regulated emissions (smoke, NO<sub>x</sub>, CO (carbon monoxide), THC (hydrocarbons)) characteristics of blends in diesel fuel of coffee, cardoon and brassica biodiesel.

**Table 2**  
Engine Specifications of AVL Single Cylinder Research Engine 5402.

Engine type	4-stroke water cooled Diesel
Manufacturer	AVL
Model	5402
Number of cylinders	1
Maximum power	18 kW
Bore	85 mm
Stroke	90 mm
Connecting rod	138 mm
Displacement	510 cm <sup>3</sup>
Compression ratio	17.1:1
Combustion chamber	Bowl with valve pockets and flat head
Injection system	Common rail
Max. injection pressure	1300 bar
Number of nozzles	5
Nozzle diameter	170 μm
Spray angle	142°

## 2. Materials and methods

### 2.1. Biodiesel production

In this research three biofuels derived from three oleaginous species of great interest, brassica and cardoon seed and waste coffee have been characterized in order to assess the potential of them for the production of biodiesel. The biodiesels were provided by the Institute of Food Production (ISPA-CNR Sciences) and method which is described in [18].

### 2.2. Engine and dynamometer

The experimental set up has been realized on a four stroke and common rail AVL single cylinder research engine 5402. The technical features of the engine are reported in Table 2. The motor shaft is coupled to an eddy current dynamometer (SYSTEM ANTRIEBSTECHNIK), which acts as necessary by the electric motor in the execution of motored cycles. The control unit and the dynamometer are interfaced with the test bench (AVL EMCON series 300). By using of this test bench the values for the rotation speed, the driving /braking torque and the load can be monitored.

### 2.3. Instrumentation

Fig. 1 shows a schematic diagram of engine setup and its instrumentation. The fuel injection system is a common rail type, which feeds an injector to five holes of a diameter equal to 170 μm. ETK interface manages, through a dedicated PC, the engine control unit (BOSCH EDC15C7) and therefore it is possible to monitor the fuel injection parameters, in particular the pressure, the injection advance with respect to TDC and the scope introduced into the combustion chamber in a cycle.

A piezoelectric sensor (AVL QC33C), equipped with a charge amplifier (AVL 3066A01), was used to measure the pressure inside the combustion chamber. Two piezo resistive sensors allow the estimation of the absolute pressure of the fuel injection (KISTLER 4067A2000) and the pressure upstream of the cylinder (KISTLER 4045A2). Both sensors mentioned above are connected to a voltage amplifier (respectively, KISTLER 4618A2 and 4643). The sampling of the pressure signals takes place on an angular basis, provided by an encoder AVL 364C, which determines the acquisition of the signals in term of the time intervals corresponding to 0.2° CA. The data acquisition card PCI 6251 LABVIEW characterized by a sampling frequency of 300 kHz was used to sampling.

The measurements of the temperatures of the coolant and exhaust gas which took place by means of thermocouples, have allowed to ascertain the correct operation of the engine. Thermocouples of the same

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