THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 1 - 2015, ISSN 1453 – 083X

USE OF ALTERNATIVE FUELS IN ROAD TRANSPORT AND ITS ENVIRONMENTAL EFFECTS. A LITERATURE REVIEW

Dan SCARPETE[a], Cristian MUNTENIȚĂ[a]*, Marina BUNEA[b]
[a] “Dunarea de Jos” University of Galati, Faculty of Engineering,
Domneasca Street, 47, RO-800008, Galati, Romania
[b] Cahul State University “Bogdan Petriceicu Hasdeu”, Faculty of Economy,
Mathematics and Computer Science, Republic of Moldova
* Corresponding author: cristian.muntenita@ugal.ro

ABSTRACT

This paper presents a literature review on use of alternative fuels in road transport, in respect of their performance and emission in diesel engines/vehicles. The major limitations of vegetable oils as fuel in diesel engines are their high viscosity and poor volatility, which lead to severe engine deposits, injector coking, and piston ring sticking. Transesterification reaction reduces the viscosity of vegetable oils, and the result of this reaction is biodiesel. In general, engine power dropped due to the lower heating value of biodiesel. A proper injection timing, by advancing the start of fuel injection by 1-2°BTDC, determined that all changes in engine emission are according to chemical and physical properties of the tested fuels.

KEYWORDS: diesel engine, vegetable oils, biodiesel, emission

1. Introduction

Our society is highly dependent on petroleum for its activities, about 90% of it being used as an energy source for transportation, heat and electricity generation [1].

The extensive use of fossil resources and especially of petroleum and its derivatives as fuel has given rise to serious environmental concerns related mainly to the production of harmful gases like SO_x, NO_x, and CO_x, which are mainly held responsible for several environmental problems [2]. Conventional diesel fuel originating from crude oil is responsible for greenhouse gas (GHG) emissions that contribute to global warming; around ¼ of the GHG emissions in Europe are caused by the transport sector, including passenger cars [3].

Diesel engines are more efficient than gasoline engines of the same power [4] and vehicles powered by a diesel engine are considered one of the primary sources of air pollution, especially in metropolitan areas [5]. The problem associated with the emissions of smoke, PM, sulfur oxide (SO_x), PAHs, and odor from the exhaust of diesel engines has been widely been a concern in many countries [6].

The use of renewable energies is considered as a viable solution for a sustainable transport future [7]. An increased usage of biofuels can contribute to reduce CO_2 emissions in road traffic. Directive 2009/28/EC on the promotion of renewable energy set a mandatory 10% minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020 [8].

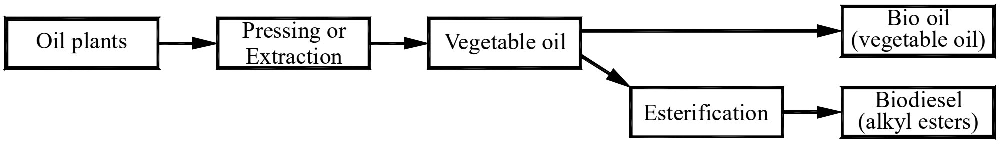

Fig. 1. *Conversion route from oil plants to biofuels (adapted from [10])*

This paper aims to present a literature review on use of alternative fuels in road transport, in respect of their performance and emission in diesel engines/ vehicles.

Currently, transportation fuels based on biomass (i.e., biofuels) are identified as first and second generation biofuels [9]. Among the most common types of first generation biofuels for diesel engines are biodiesel and straight vegetable oils. Figure 1 presents the main routes to produce vegetable oil and biodiesel [10]. Biofuels are favorable choice of fuel consumption due to their renewability, biodegradability and generating acceptable exhaust gases [11].

2. Vegetable oil as diesel fuel

Many researchers have concluded that vegetable oils hold promise as alternative fuels for diesel engines [12]. Vegetable oils have [13, 14]:

- high biodegradability;
- high calorific value: high energy density;
- ready availability and renewability;
- are neither harmful nor toxic to humans, animals, soil nor water;
- are neither flammable nor explosive, and do not release toxic gases;
- reduced emission, particularly CO_2, SO_x, soot and aromatic compounds.

The major limitations of vegetable oils for their use as fuel in diesel engines are their high viscosity and poor volatility, which deteriorate the atomization, evaporation and air-fuel mixture formation leading to improper combustion and higher smoke emission [15]. The increased viscosity and low volatility of vegetable oils lead also to severe engine deposits, injector coking, and piston ring sticking [12].

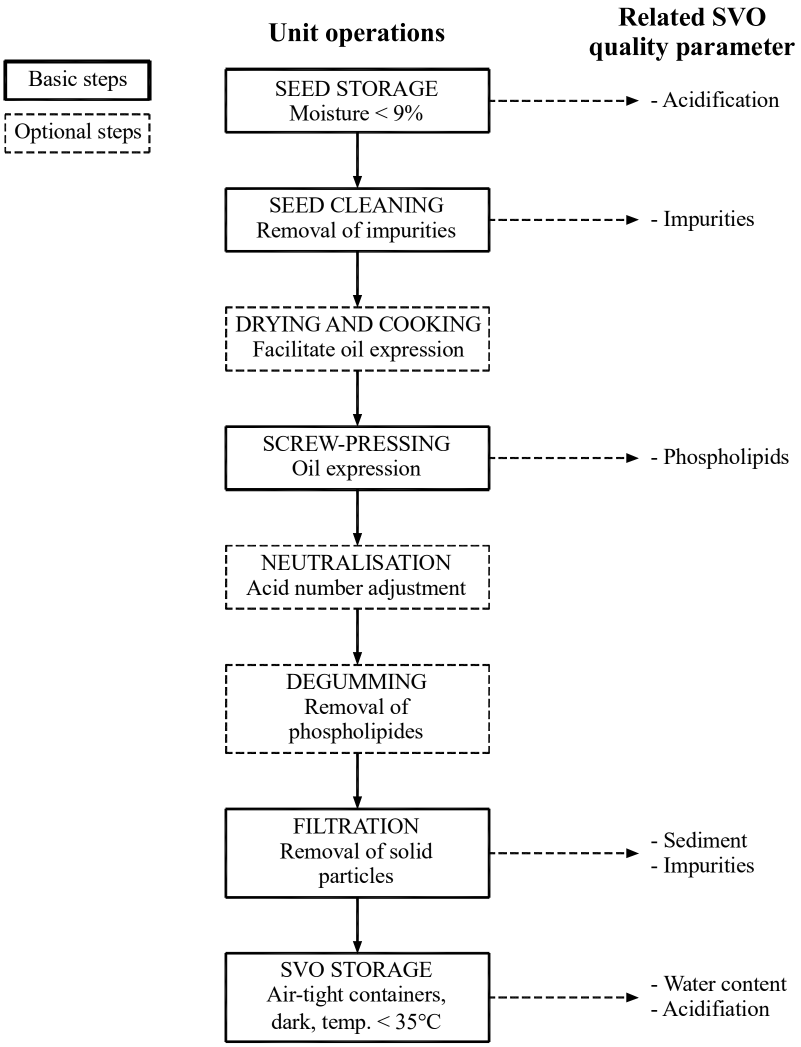

Fig. 2. *Straight vegetable oils quality in relation to the production process* [16]

Straight vegetable oils (SVO) are usually produced by mechanical extraction of oil from an oil-bearing biomass as feedstock [16]. The quality of SVO for fuel use is strongly influenced by both the quality of the feedstock and the processing conditions. Oilseeds come usually from dedicated crops (sunflower, rapeseed, oil palm, Jatropha curcas, etc.). There are five main operations in the SVO production process that govern fuel quality and which need to be carefully managed (Fig. 1).

In order to use vegetable oil as fuel, a professional engine conversion is strongly recommended [17]. This conversion often includes installing a second fuel tank, allowing the engine to start and shut down on biodiesel or diesel fuel. The basic idea is to use only preheated vegetable oil to at least 60 °C in order to reduce the oil viscosity (Fig. 2).

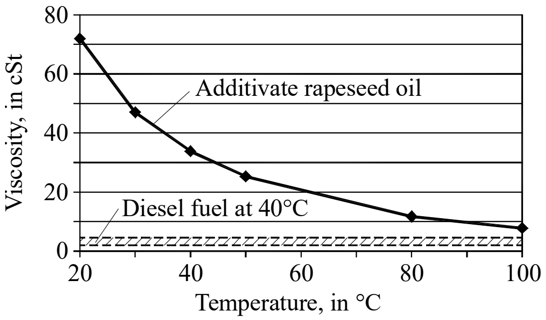

Fig. 2. *Viscosity of rapeseed oil versus temperature (adapted from [18])*

Current interest in the use of pure plant oils is growing, that can be used in pure form but can also be blended into diesel up to 25%vol [19]. These blends can in principle be used in unmodified direct injection diesel engines. Also higher percentages blends and blends with different oils and e.g. ethanol are possible. Table 1 presents an overview regarding the effects of pure plant oils (pure and blends) on the diesel engine emissions, according to the literature cited in [19].

3. Biodiesel

Crude vegetable oils are inferior as fuel in terms of viscosity, heating value, freezing point, etc. [20]. In order to reduce viscosity, vegetable oils are converted into esters by transesterification reaction [1]. The result of transesterification reaction (Fig. 3) is biodiesel, as a fuel comprised of mono-alkyl esters of long chain fatty acids derived esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100 [22].

Because the biodiesel viscosity is almost twice higher than the diesel fuel viscosity (according to Standard EN 14214:2003, the biodiesel viscosity at 40 °C is 3.5-5.0 mm^2/s [23]), biodiesel is currently used in blends with diesel fuel.

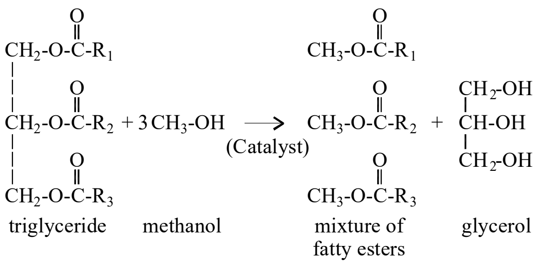

Fig. 3. *Transesterification reaction* [21]

Biodiesel can be produced from various vegetable oils, waste cooking oils or animal fats. The fuel properties of biodiesel may be changed when different feedstocks are used [24]. However, biodiesel production is highly dependent on many local variables such as feedstock and land availability, costs associated with feedstock procurement, government subsidies and tax reductions as well as interactions with the food industry [25].

Table 1. *Effects of virgin plant oil (pure & blends) on diesel engine emissions* [19]

Blend, %	**Regulated emissions**				**References cited in [19]**
	CO	**HC**	**NO$_x$**	**PM**	
100	–	–	+	–	Lance 2004 (LDV)
100	+	+	+&–	+ 3)	Aberson 2004 2)
30			–	+	Senda 2004 (HDV)
100	–	–	+	+ 1)	Kumar 2001
100	+		+	+ 1)	Niemi 1997
50/100	–	+	+	+ 1)	Ziejewski 1992
100	–	–	+	–	Hammerlein 1991 (DI)

1) Smoke; 2) Unclear whether this information is based on test data; 3) Soot
+ = positive/yes; – = negative/no
LDV - Light Duty Vehicle; HDV - Heavy Duty Vehicle; DI - Direct Injection diesel engine

The main stages of the fuel systems for biodiesel from vegetable oil and waste cooking oil are shown in Figure 4.

A survey on 27 literatures [26] to study the effect of pure biodiesel on engine power, showed that 70.4% of them agreed that, with biodiesel (especially with pure biodiesel), engine power will drop due to the loss of heating value of biodiesel (Table 2). However, the results reported show some fluctuation. Some authors found that the power loss was lower than expected (the loss of heating value of biodiesel compared to diesel) because of power recovery.

Table 2. *Statistics of effects of pure biodiesel on engine performances (adapted from [26])*

	Total number of references	**Increase**	**%**	**Similar**	**%**	**Decrease**	**%**
		Number		**Number**		**Number**	
Power performance	27	2	7.4	6	22.2	19	70.4
Economy performance	62	54	87.1	2	3.2	6	9.7

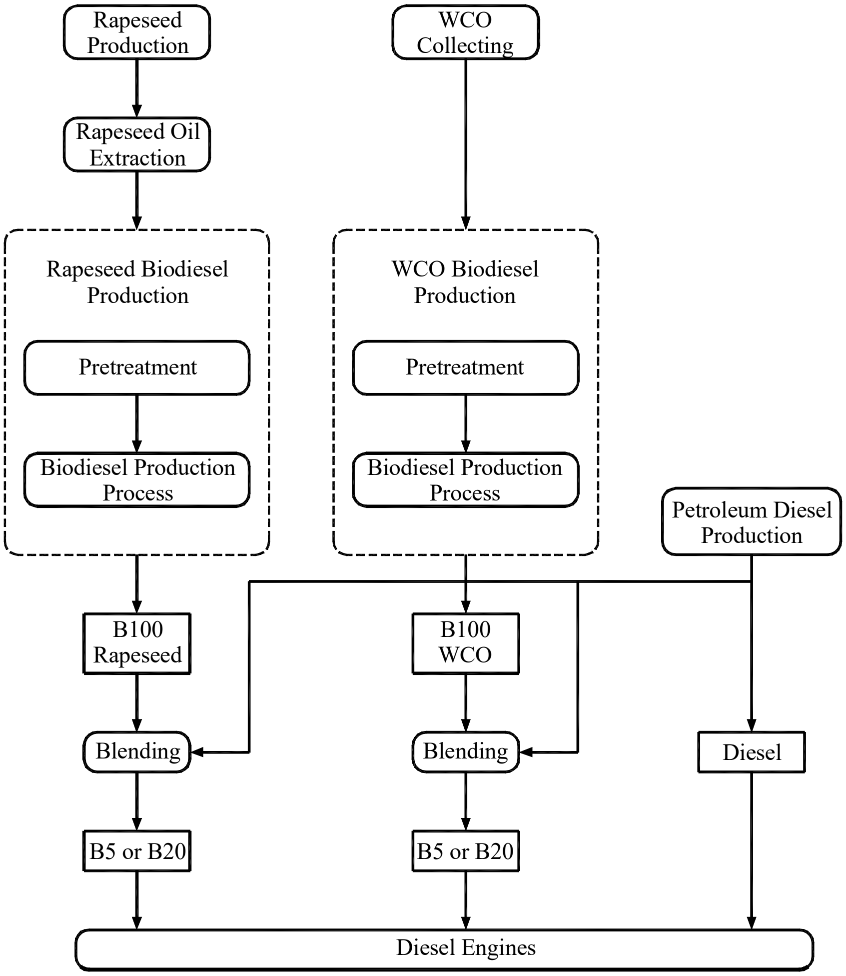

Fig. 4. *Fuel systems for biodiesel from vegetable oil (rapeseed oil) and waste cooking oil (WCO) (adapted from [25])*

Table 3 summarizes some available results of Light-Duty diesel vehicle test data for some rapeseed biodiesel blends (a minimum of 20 measurements of a particular blend were required to assess the significance of the effect) that allow one to explore the differences in the effects on emissions of the different biodiesel feedstock [27]. The emission data from Table 3 could be discussed as follows:

- HC lower for B20 and B100, but no correlation between biodiesel content in the blend and level of HC emission;
- NO_x higher than for diesel fuel for all blends, the higher content of biodiesel, the higher NO_x emission;
- CO emission is random, lower for B20, but higher for B30;
- Particulate matter (PM) emission is not significant versus diesel fuel. However, a very slight increase of PM for biodiesel blends is observed.

The heterogeneous and uncorrelated data from the Table 3 could be due to the use of biodiesel and biodiesel blends on diesel engines tuned only for pure diesel fuel or for B5-B7 blends. Using higher percentage biodiesel blends, or even B100 fuel, on existing unmodified engines, could cause an inappropriate response of the engine in respect of torque (power) and emission.

In their experimental work, Canakci and Van Gerpen [28] found that to provide the same torque as with diesel fuel, it was necessary to inject 13 to 14% more biodiesel and for that, the injection timing was advanced between one and two degrees. The combustion characteristics of the fuels used, according to the physical properties of the fuels, self-timing of the injection pump, and injector nozzle opening pressure (20.7 MPa), are presented in Table 4.

According to Van Gerpen [29], the cetane number (CN) for biodiesel blends is calculated using the following linear regressions:

- for 20% SME

$$CN = 0.089 \cdot (\%\,\text{blend}) + 42.6 \qquad (1)$$

- for 20% YGME

$$CN = 0.2 \cdot (\%\,\text{blend}) + 42.6 \qquad (2)$$

Table 3. *Effects and significance of rapeseed biodiesel blends on the relative vehicle emissions for chassis dynamometer data with light-duty vehicles (adapted from [27])*

Emission	Biodiesel blend	Effect ± 95% confidence interval	Number of measurements	Significant effect *
HC	B10	+4.9 ± 5.0%	27	NS
HC	B20	-10.6 ± 7.9%	28	Lower
HC	B30	+3.1 ± 5.7%	26	NS
HC	B50	+1.2 ± 15.7%	29	NS
HC	B100	-20.9 ± 19.3%	32	Lower
NO_x	B10	+0.9 ± 1.8%	27	NS
NO_x	B20	+3.2 ± 4.8%	28	NS
NO_x	B30	+4.5 ± 2.2%	26	Higher
NO_x	B50	+5.2 ± 4.3%	29	Higher
NOx	B100	+5.7 ± 5.5%	33	Higher
CO	B20	-9.6 ± 6.5%	28	Lower
CO	B30	+11.6 ± 6.4%	23	Higher
CO	B50	+2.3 ± 16.6%	26	NS
CO	B100	-4.3 ± 19.3%	32	NS
PM	B20	-0.8 ± 9.5%	21	NS
PM	B50	+6.4 ± 18.7%	20	NS
PM	B100	+4.5 ± 11.0%	26	NS

* NS – not significant

Table 4. *Combustion characteristics of the fuels (adapted from [28])*

Fuel	Start of fuel injection (°BTDC)	Start of combustion (°BTDC)	Ignition delay (°)	Cetane number	Kinematic viscosity at 40 °C (cSt)
No. 2 Diesel	13.50	7.42	6.09	42.6 *	2.8271
20% SME	14.40	8.33	6.07	44.38 **	3.1071 **
20% YGME	14.60	8.50	6.10	46.6 **	3.2871 **
SME	16.18	10.83	5.34	51.5 *	4.2691
YGME	17.05	11.58	5.46	62.6 *	5.1643

SME – soybean oil methyl ester; YGME – yellow grease methyl ester

* Cetane number determined according to ASTM D613 [28]; ** Calculated using linear regression

Table 5. *Average percent changes in the engine emissions with Tukey grouping statistical results (adapted from [28])*

Fuel type	Change in CO %	Change in CO_2 %	Change in HC %	Change in NO_x %	Change in SN %
20% SME	-7.5	-0.04	-3.1	+1.5	-15.8
20% YGME	-7.0	-0.06	-2.3	+1.1	-16.8
SME	-18.2	+1.8	-42.5	+13.1	-61.1
YGME	-17.8	+1.2	-46.3	+11.6	-64.2

SN – Bosch smoke number

According to data from [30], for methyl ester of soybean oil, the kinematic viscosity for biodiesel blends may also be calculated using linear regression. Thus, the linear regressions, to estimate the kinematic viscosity (KV), at 40 °C, for the biodiesel blends from [28], are as follows:

- for 20% SME

$$KV = 0.014 \cdot (\%\ \text{blend}) + 2.8271 \qquad (3)$$

- for 20% YGME

$$KV = 0.023 \cdot (\%\ \text{blend}) + 2.8271 \qquad (4)$$

The average percent changes in the engine emissions, at engine full load for peak torque condition (1400 rpm and 258 Nm), are shown in Table 5. It can be noticed that all changes in engine emission are according to chemical and physical properties of the tested fuels: the higher oxygen content (i.e. for the biofuels and their blends), the lower CO and SN emission and higher NO_x emission. These correlated results could be due to a proper injection timing by advancing the start of fuel injection by 1-2°BTDC.

4. Conclusions

Vehicles powered by a diesel engine are considered one of the primary sources of air pollution, and the use of alternative fuels is considered as a viable solution for a sustainable transport future.

Vegetable oils are a promising alternative fuel for diesel engines due to their high biodegradability, ready availability and renewability and their reduced emission. The major limitations of vegetable oils for their use as fuel in diesel engines are their high viscosity and poor volatility, which lead to severe engine deposits, injector coking, and piston ring sticking.

By the transesterification reaction, the viscosity of vegetable oils is reduced, and the result of this reaction is biodiesel.

A literature survey pointed out that in 70.4% of studied cases, engine power dropped due to the lower heating value of biodiesel. However, it was found that the power loss was lower than expected because of power recovery.

The emission data from some available literature results for Light-Duty diesel vehicle tests fuelled with rapeseed biodiesel blends showed that there is no correlation between biodiesel content in the blend and level of HC, CO and PM emission.

A proper injection timing, by advancing the start of fuel injection by 1-2°BTDC, determined that all changes in engine emission are according to chemical and physical properties of the tested fuels.

Acknowledgement

The work has been funded by the Sectorial Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/ 159/1.5/S/132397.

References

[1]. **Feddern V. *et al.***, *Animal Fat Wastes for Biodiesel Production*, Biodiesel, Feedstocks and Processing Technologies.

[2]. **Vonortas A., Papayannakos N.**, *Comparative analysis of biodiesel versus green diesel*, WIREs Energy Environ 2014, doi: 10.1002/wene.78.

[3]. **Hurtig O. *et al.***, *Alternative fuels from forest residues for passenger cars - an assessment under German framework conditions*, Energy, Sustainability and Society, 4:12, A Springer Open Journal, 2014.

[4]. **Alfieri E.**, *Emissions-Controlled Diesel Engine*, Doctoral thesis, Diss. ETH No. 18214, Swiss Federal Institute of Technology Zurich, 2009.

[5]. **Lin C.-Y., Wang K.-H.**, *Effects of a Combustion Improver on Diesel Engine Performance and Emission Characteristics When Using Three-Phase Emulsions as an Alternative Fuel*, Energy Fuels, 18 (2), p 477-484, 2004.

[6]. **Lin Y.-C. *et al.***, *Approach for Energy Saving and Pollution Reducing by Fueling Diesel Engines with Emulsified Biosolution/ Biodiesel/Diesel Blends*, Environ. Sci. Technol., 42 (10), p 3849-3855, 2008.

[7]. **Nanaki E. A., Koroneos C. J.**, *Comparative LCA of the use of biodiesel, diesel and gasoline for transportation*, 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS), Nisyros-Greece, 4-6 June, 2009.

[8]. **Directive 2009/28/EC**, *On the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 2009.04.23*, Official Journal of the European Union, 5.6.2009; L 140.

[9]. Cherubini F., Jungmeier G., *LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass*, International Journal of Life Cycle Assessment, 15, p. 53-66, 2010.
[10]. Hamelinck C. N., *Outlook for advanced biofuels*, Universiteit Utrecht, Nederlands, 2004.
[11]. Nigam P. S, Singh A., *Production of liquid biofuels from renewable resources*, Progress in Energy and Combustion Science. 2010, In press.
[12]. Canakci M., Van Gerpen J., *Biodiesel production from oils and fats with high free fatty acids*, Transactions of the ASAE, Vol. 44(6), p. 1429-1436.
[13]. Breton J. *et al.*, *Renewable energy sources and technologies on farm systems, focusing on Danish scenario*, The Royal Veterinary and Agricultural University, Denmark, 58, p. 13, 2004.
[14]. Ma F., Hanna M. A. *Biodiesel production: a review*, Journal Series #12109, Elsevier Science B.V., 4, p. 3, 1999.
[15]. Hossain A. B. M. S., Boyce A. N., *Biodiesel production from waste sunflower cooking oil as an environmental recycling process and renewable energy*, Bulgarian Journal of Agricultural Science, 15 (No 4), p. 312-317, 2009.
[16]. Blin J. *et al.*, *Characteristics of vegetable oils for use as fuel in stationary diesel engines - towards specifications for a standard in West Africa*, Renewable and Sustainable Energy Reviews, 22, p. 580-597, 2013.
[17]. Kurki A., Hill A., Morris M., *Biodiesel: The Sustainability Dimensions*, A Publication of ATTRA, NCAT, 2006.
[18]. Moise D. C., Scarpete D., *Emissions from a railway engine fueled with rapeseed oil*, XVI International Scientific and Technical Conference – trans & MOTAUTO'09, Sunny Beach, Bulgaria, 2009.
[19]. Schmidt L., *Biodiesel vehicle fuel: GHG reductions, air emissions, supply and economic overview*, Discussion paper C3-015, Climate Change Central, 2004.
[20]. Arbab M. I. *et al.*, *Fuel properties, engine performance and emission characteristic of common biodiesels as a renewable and sustainable source of fuel*, Renewable and Sustainable Energy Reviews, 22, p. 133-147, 2013.
[21]. Van Gerpen J. *et al.*, *Biodiesel Production Technology*. NREL/SR-510-36244, Contract No. DE-AC36-99-GO10337, 2004.
[22]. ASTM D 6751 – 02, *Standard Specification for Biodiesel Fuel (B 100) Blend Stock for Distillate Fuels*.
[23]. EN 14214:2003 (E), *Automotive Fuels - Fatty Acid Methyl Esters for Diesel Engines - Requirements and Test Methods*.
[24]. Ozsezen A. N., Canakci M., *Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters*, Energy Conversion and Management, 52, p. 108-116, 2011.
[25]. Ozata I. *et al.*, *Comparative Life Cycle Assessment Approach for Sustainable Transport Fuel Production from Waste Cooking Oil and Rapeseed*. January 2009.
[26]. Xue J., Grift T. E., Hansen A. C., *Effect of biodiesel on engine performances and emissions*, Renewable and Sustainable Energy Reviews, 15, p. 1098-1116, 2011.
[27]. Anderson L. G., *Effects of Biodiesel Fuels Use on Vehicle Emissions*, Journal of Sustainable Energy & Environment, 3, p. 35-47, 2012.
[28]. Canakci M., Van Gerpen J., *Comparison of engine performance and emissions for petroleum diesel fuel, yellow-grease biodiesel and soybean-oil biodiesel*, Transactions of the American Society of Agricultural Engineers, 46, p. 937-944, 2003.
[29]. Van Gerpen J. H., *Cetane Number Testing of Biodiesel*.
[30]. Yoon S. H., Park S. H., Lee C. S., *Experimental Investigation on the Fuel Properties of Biodiesel and Its Blends at Various Temperatures*, Energy & Fuels, 22, p. 652-656, 2008.